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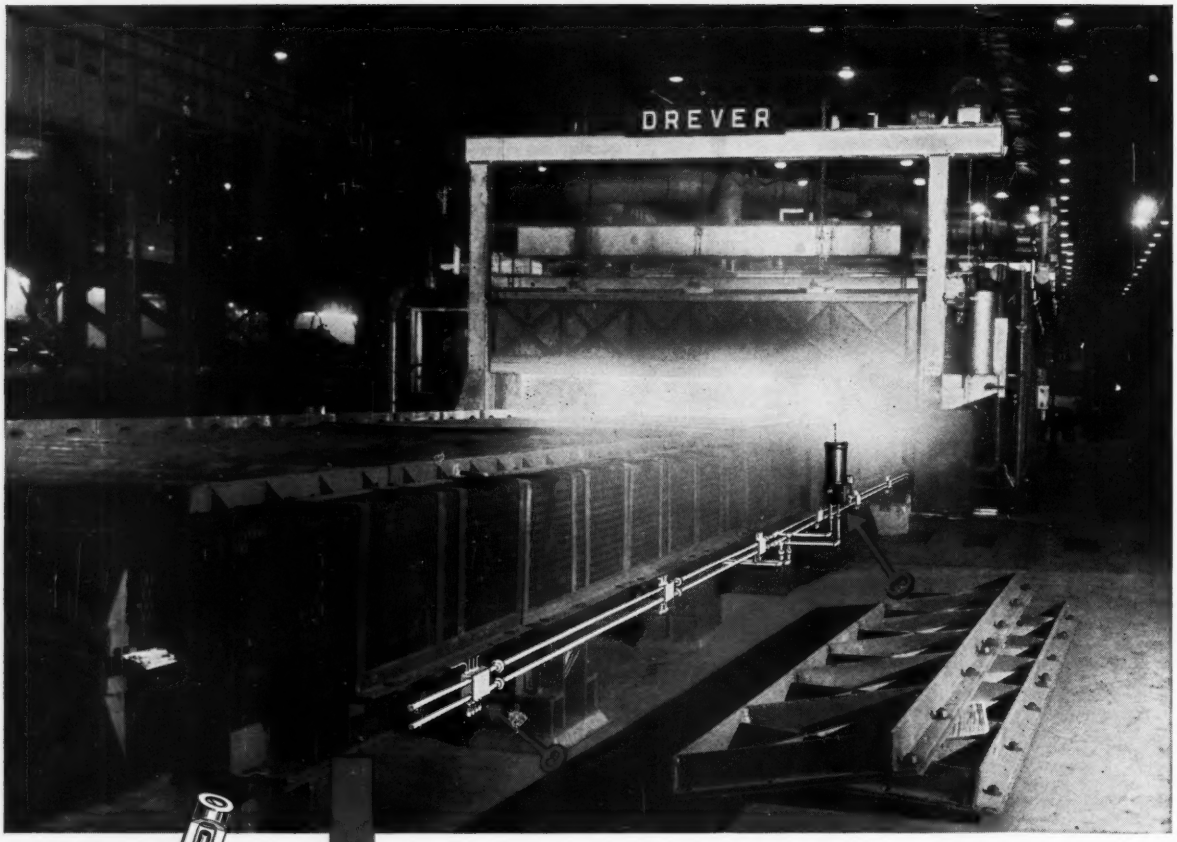
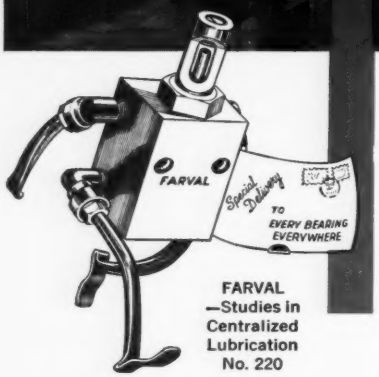
RESEARCH APPLICATION EDUCATION MAINTENANCE

Cutting Oils Speed Sawing

JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS





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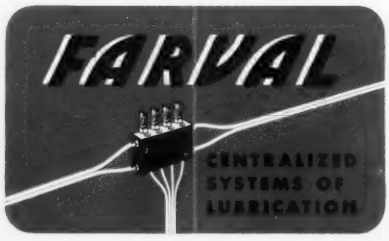

LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

Volume 14, No. 6

June, 1958

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Cover Picture: Application of soluble oil cutting fluid in cut-off power sawing increases production through faster cutting rates and longer tool life. (Courtesy The DoAll Company)

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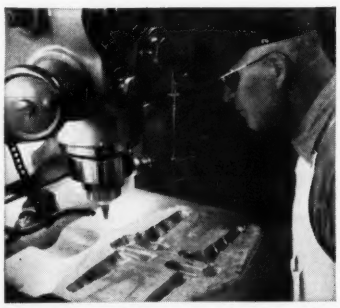

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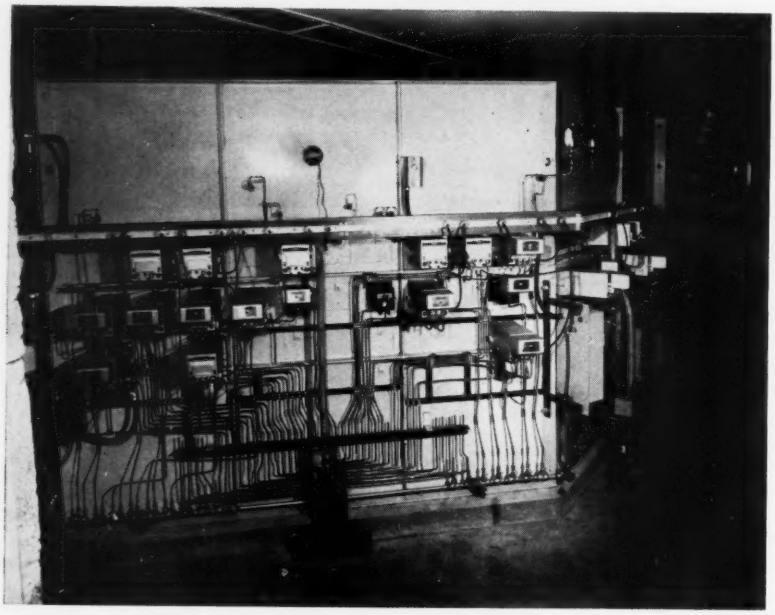
Nylon replaces copper for tubing used in pneumatic activated measuring and control devices at phthalonitrile plant of Barrett Division, Allied Chemical. The unique application of nylon is less expensive, easier to install and brings increased resistance to corrosion.



Control Panel Uses Nylon To Cut Automation Costs

Color-coded nylon tubing has replaced copper in an instrument-air control panel installed at Allied Chemical's phthalonitrile plant, Edgewater, N. J. It is the first such system to utilize nylon in the automatic measure and control of liquid flow, temperature and pressure.

The nylon is used in conjunction with pneumatic activated measuring and control devices to register physical conditions at specific measuring points on the central control panel. (Although a number of measurements are performed electrically at the valves, these are translated into air pressure by transduction.) Use of this system provides regulation of plant processes involving ammonia and other harsh chemical materials more safely than by direct measurement, and less expensively than by an electrical system.

For this first-of-its-kind installation, ¼-in. OD tubing with a 30 mil wall is utilized. Maximum working pressure for this size is 800 psi and burst pressure 1600 psi. Since the system utilizes only 3 to 15 psi air pressure, the nylon is well within safety requirements.

Installation is facilitated by the fact that nylon tubing can be bent by hand easily and held in place by quickly installed clips. In addition, nylon flares more easily than copper, can be used with any conventional metal fittings, and can be inexpensively solvent-welded.

New Tax Rule

A new Internal Revenue Service ruling on the deductibility of education expenses will aid many engineering and scientific employees who pay all or part of their tuition for continued education. Under the new regulations, the purpose of the individual in seeking additional education will be the determining factor as to whether or not the expenses for going to school are deductible for income tax purposes.

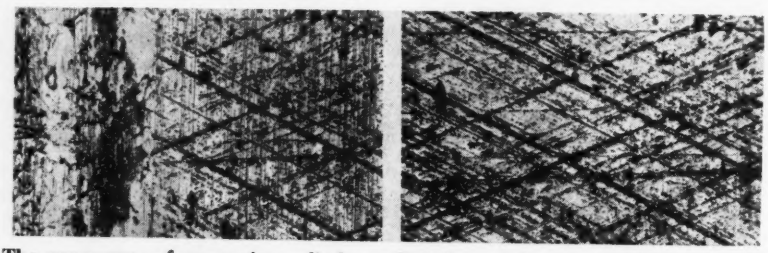
Plastic Replicas Provide Measure Of Engine Wear

The search for a better understanding of what causes scuffing in engine cylinders has led to the use of plastic replicas for following the progress of wear in engine cylinders, microscopists at Battelle Memorial Institute report. The plastic replicas, made after successive steps in an engine run, are prepared for examination under the light microscope.

To make replicas of engine cylinder walls, scientists at the Columbus, Ohio research center remove the engine head at set intervals and lower the pistons. Replicas are made by dipping sheets of cellulose acetate in dioxane and pressing them against the cylinder walls. Refinements in the basic technique make it possible to obtain replicas almost completely free of bubbles and other defects. A thin layer of gold is evaporated on replicas of particular interest to enhance reflectivity and contrast when they were examined under the light microscope.

The engine being studied is run under increasingly severe conditions until scuffing occurs. Since the series of replicas provide a graphic history of the cylinder surfaces during the engine run, microscopists are able to view in retrospect the areas in which scuffing occurred. The same areas on replicas made after successive steps are located by matching the honing patterns that recurred in each replica taken.

A. P. Young, the Battelle microscopist who conceived the idea of this use for replicas, says that replicas for light microscopy have at least two advantages over conventional light microscope techniques: (1) Replicas can be used for microscopic examination of surfaces inaccessible because of size or shape to direct examination. (2) A series of replicas taken at stages during a test constitutes a graphic history of the sample being studied. This method of examination may be used not only to investigate wear but any problem in which the origin of surface features, such as fatigue cracks, is of interest.



The same area of an engine cylinder wall before and after scuffing occurred. The picture on the left was made at an intermediate state during the engine run and before scuffing occurred. Rough vertical bands in the picture on the right, which was taken later, indicate the occurrence of scuffing.

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Engineering Grant of $106,600 Awarded to Case Institute

Case Institute of Technology has been granted $106,600 from the Carnegie Corporation of New York for a one-year program of study and action aimed at producing major improvements in engineering education.

The grant was announced by Dr. John A. Hrones, vice-president for academic affairs at Case, who will be chairman of the committee which will direct the study.

Among the aims of the program will be the breaking down of traditional barriers between specialized engineering fields, the development of a mathematics program geared to the opportunities of the age of computers, and introduction of the professional problems of engineering at an early stage in the student's education.

Need for the program, says Dr. Hrones, arises from our age of an "exploding technology," characterized by a rapid growth in scientific knowledge, and increasingly complex industrial, political, and economic life. These demand even greater educational preparation in the fields of engineering, science, and management.

Members of the faculty at large and the administration will make up an overall executive committee administering the grant. Additional faculty committees in five separate areas for study will be formed, and these committees will call upon many outside specialists. Results of the studies will be made available to other engineering institutions in order to aid engineering education on a national basis.

Catering Service For Diesels

A new mobile refueler being used by the Elgin, Joliet & Eastern Railway in its Kirk Yards at Gary, Ind., allows the road to fuel its switching locomotives while they work.

This means fewer trips back to permanent yard installations for minor servicing, fuel, and sand, needed by the diesel switchers for wheel-to-rail traction.

Built by Farrell Manufacturing Company, Joliet, Ill., producer of truck tanks, the unit also carries radiator water, compressor oil, lubrication oil, and even ice for the crew's drinking water.

By using the refueler to service diesel locomotives and their "hump" trailers — units equipped with four traction motors for extra power at low speeds — the railroad can keep a locomotive in service with fewer interruptions for service at permanent fueling and sanding stations in the yard.

The locomotive catering unit has a capacity of 1,500 gallons of fuel and carries 27 cubic feet of sand in a special tank. The sand is blown directly into locomotive hoppers using air drawn from the train's air brake system.

On a typical assignment, the refueler is driven right to the locomotive work site. The operator inserts the unit's fuel hose into the diesel's tanks, and starts the fuel pump. Servicing takes only 20-25 minutes.

While the fuel tanks are being filled — an automatic cut-off in the hose nozzle prevents overflowing—the operator couples a hose to the locomotive air line and blows sand out of the refueler's sand tank, through another hose, directly into the engine's sand boxes.

Diesel switching locomotive is refueled and "sanded" simultaneously at Kirk Yard of the Elgin, Joliet & Eastern Railway in Gary. The far hose pumps diesel fuel into the locomotive tanks while operator fills the sand boxes with sand — needed by the switcher for traction when starting and stopping — into a hopper.

Other roads are using a number of the refuelers or have them on order, according to Richard L. Duchossois, Farrell president. He added that one road is servicing 35 switching locomotives which operate in a 100-square mile area with a single refueler.

"Reports we've received thus far from the railroads have been most encouraging," Duchossois said.

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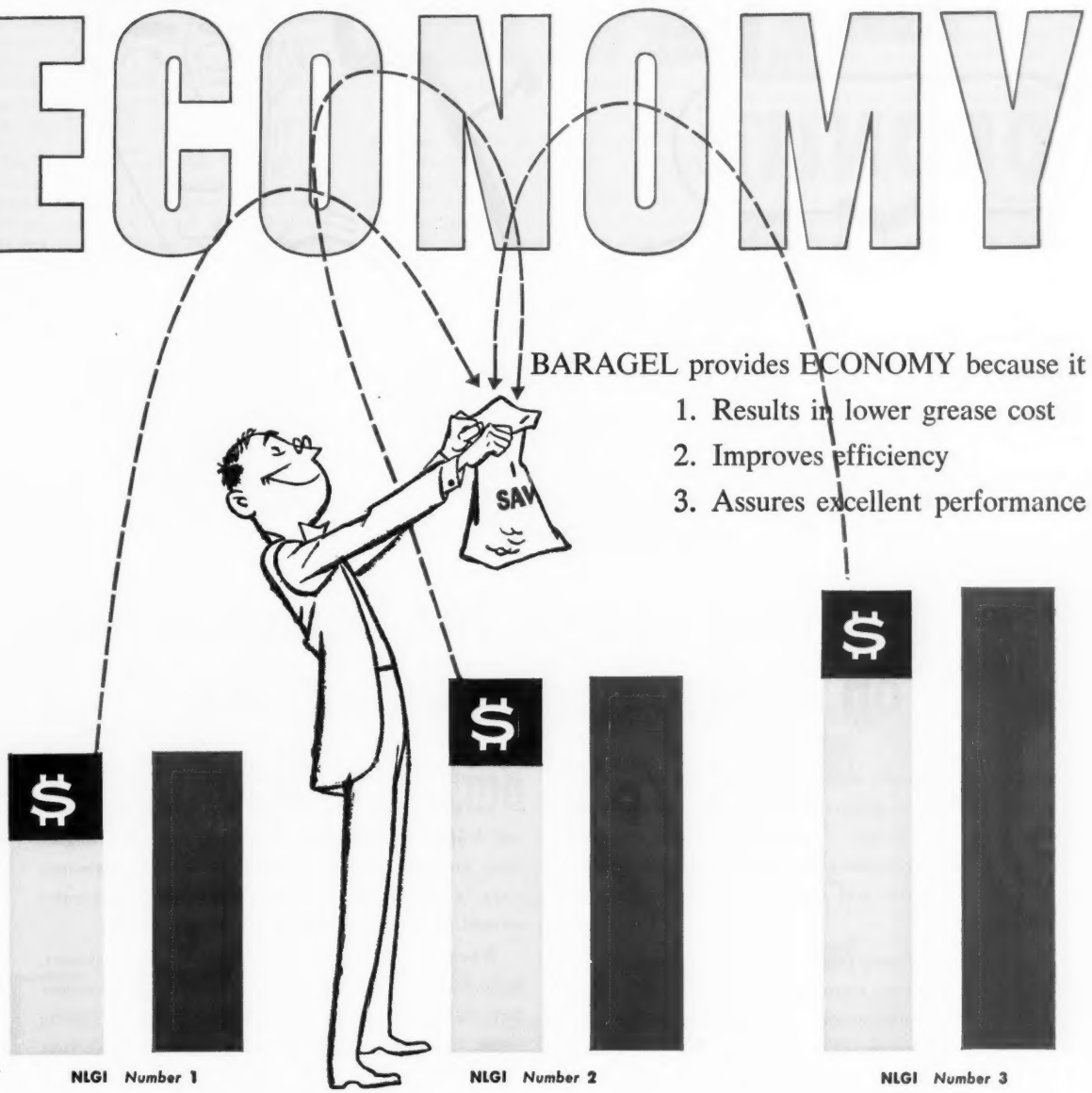

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PERSONALS

New officers and trustees of the National Screw Machine Products Association were elected at the association's 25th anniversary convention at Chicago's Drake Hotel on May 2. New president is C. J. Baumgart, president of Screw Machine Engineering Company, Chicago. Elected vice president was Leonard R. Schaffer, president, Mechanical Art Works, Inc., Newark, N. J., while Roland G. Herker, vice president and treasurer of Herker Screw Products, Inc., Milwaukee, was elected treasurer. Re-elected were Orrin B. Werntz as counsel and executive vice president of the Association, and Margaret S. Ballinger as secretary.

The appointment of Dale C. Baxter as director Engineering Department of the Wonder Building Corporation of America, Chicago manufacturer of pre-engineered trussless steel buildings and roof systems, has been announced. Baxter has been a member of the firm's engineering department for the past four years. Originally employed in product development work, he later became a member of the firm's general engineering department. His new position puts him in charge of all engineering activities of the company.

Col. Robert M. Burnett, United States Army, Ret., formerly Executive Officer in the Office of Assistant Secretary of the Army, has joined Flexonics Corporation, Maywood, Illinois, as planning coordinator and assistant to the president. In his new position, Burnett will assist Flexonics' President John F. P. Farrar with planning and development of products, long term business planning and general administrative matters for the company's eight plants and national field organization.

BAUMGART

BAXTER

W. Allen Taft, director of sales of du Pont's photo products department, has been named director of sales of the company's Petroleum Chemicals Division. He succeeds W. Samuel Carpenter, III, who was recently appointed assistant general manager of the electro-chemicals department.

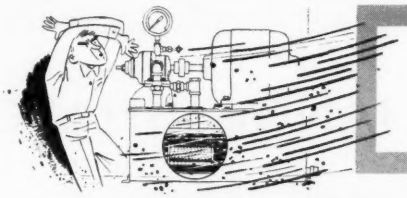
A. D. Blake, sales engineer for the spectrochemical equipment line manufactured by Baird-Atomic, Inc., Cambridge, Mass., has been assigned to handle the Chicago area.

R. E. Leach has been appointed assistant manager for the Willow Island and Marietta, Ohio, plants of the Organic Chemicals Division, American Cyanamid Company.

Appointment of Dr. William S. Gallaway as senior physicist for Beckman Instruments' Scientific Instruments Division has been announced. In his new position, Dr. Gallaway will supervise exploratory research into advanced types of analytical instrumentation for scientific, industrial and medical laboratories. He also will direct evaluation of the design and performance of new instrumentation developed by the Fullerton-based division. Dr. Gallaway moves to the new post after serving as supervisor of infrared laboratory instrument applications. Prior to joining Beckman, he was associated with Universal Oil Products, Chicago.

Howard Rambin, Jr., has been elected senior vice president in charge of Texaco's worldwide producing interests and activities. A. W. Baucum was elected vice president in charge of the domestic producing department.

The appointment of John G. Sibley to the newly created post of southern regional manager of Jefferson Chemical Company, Inc. has been announced.



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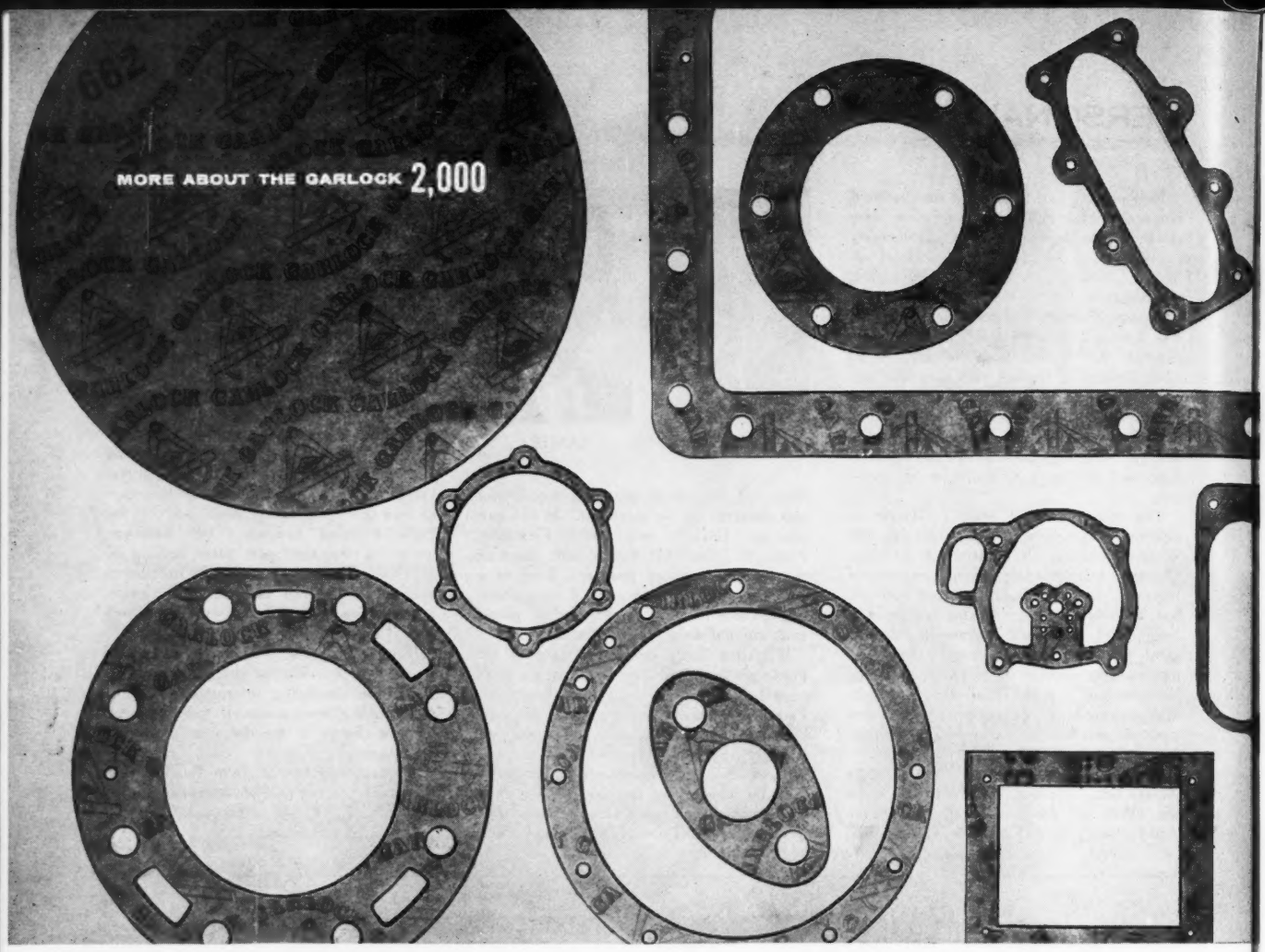

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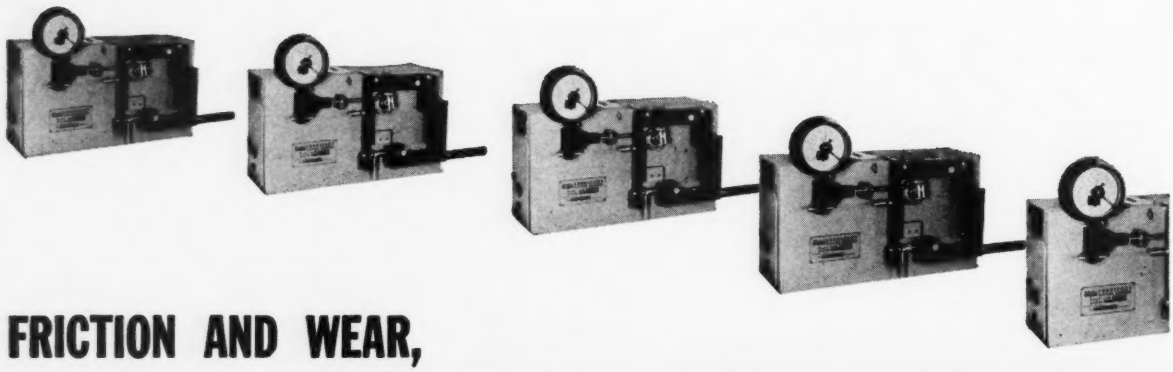


FRICTION AND WEAR, LIKE METAL FATIGUE PROBLEMS, DEMAND COMPREHENSIVE TESTING TO BREAK DOWN THE APPARENT COMPLEXITY

Complete isolation of individual effects is necessary to determine the influence of each condition on boundary lubrication

Although many complex phases of engineering have something in common, there is an uncanny parallel in the study of frictional effects and fatigue effects in metals.

The complexity of fatigue of metal problems involved such effects as metallurgical composition, geometrical shape, size, surface geometry, residual stresses, atmospheric environment, metal working and assembly-induced stresses. Since little was known about the full influence of any of these conditions on fatigue, full-scale simulated service testing of structures and assemblies allowed only composite analyses of these effects. In these composite analyses, however, large variations existed and researchers were unable to pinpoint the particular effect which accounted for the variations.

TESTING IN DETAIL PRODUCED RESULTS

With the advent of World War II, aircraft and military developments forced a more systematic approach to the problem of metal fatigue. A large number of small and relatively inexpensive testing machines were installed to investigate individual effects which were known or presumed to make up the complexity. This approach produced results.

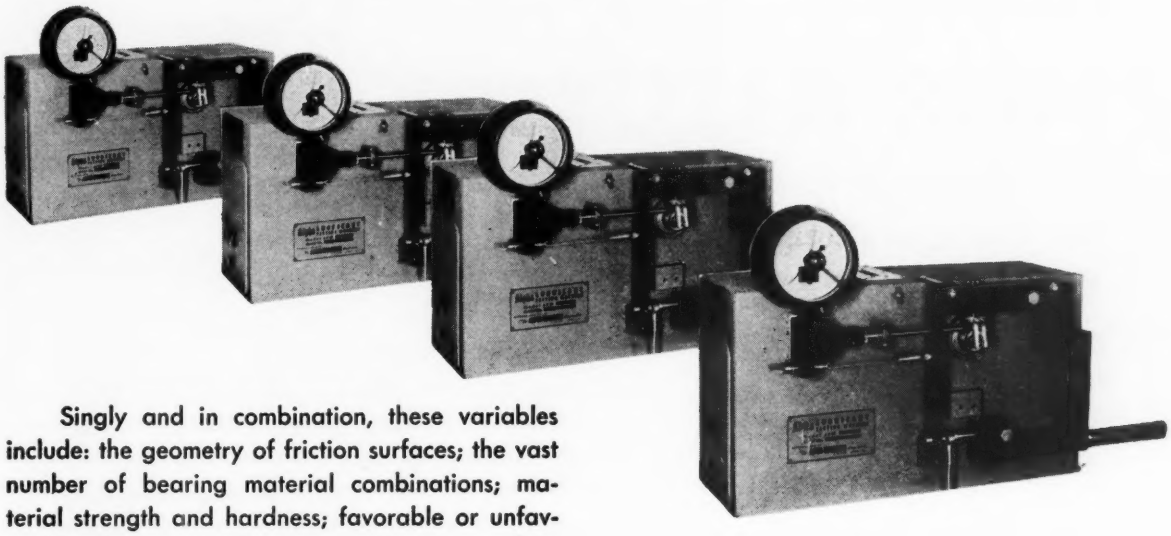
Concentrating on metallurgical composition brought about a knowledge of the decrementary effect of inclusions near the surface. Tests concentrating on geometrical shape disclosed reductions of fatigue strength due to abrupt changes of specimen contour. Surface geometry tests showed the strength-reducing effects of sharp notches. Tests for residual stresses revealed the beneficial effects of surface compression stresses and the detrimental effects of surface tension stresses. Atmospheric environment tests showed the strength-reducing effects of even minor surface corrosion.

Full-scale testing could never have isolated these effects. It wasn't until millions of hours of testing were conducted on small machines that many of the complex phases of fatigue life were cleared up. This made full-scale testing productive and economical.

SAME APPROACH NEEDED FOR FRICTION AND WEAR EFFECTS

The complexity of boundary lubrication rivals the complexity of metal fatigue. It needs, and will receive, increasing attention! Millions of hours of testing must go into the effort to isolate and determine the significance of a multitude of damaging or beneficial effects.

THE BETTER THE TESTING EQUIPMENT . . .
THE LOWER THE COST OF PRODUCTIVE RESEARCH



Singly and in combination, these variables include: the geometry of friction surfaces; the vast number of bearing material combinations; material strength and hardness; favorable or unfavorable formation of surface deposits; surface oxidation; the influence of frictional heat on the bearing metals and the lubricant; bearing pressures; sliding velocity; and so on.

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Our Bulletin #106 describes in detail the Alpha Model LFW-1 Lubrication-Friction-Wear Testing Machine. If you have not already received a copy, we will send one to you by return mail.

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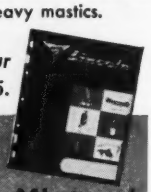

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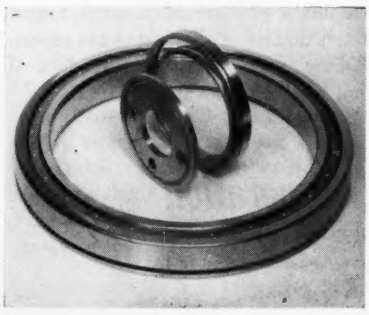
Thin-section radial ball bearings, especially designed or built to specifications, are a new addition to the line of Ann Arbor Bearing and Manufacturing Co. This company has devised thin-section techniques for bearing fabrication to eliminate warpage — the major difficulty in past development and production of bearings of this type. Developed specifically for designs where space and/or weight must be decreased, thin-section bearings will reportedly find broad application in many fields. Initial installations which have proven thin-section bearing principles have been used in aircraft equipment, portable air tools, magnetic clutches and portable chain saws. Thin-section bearings can be fabricated from almost every type of bearing material including magnetic stainless steel, non-magnetic stainless steel, SAE 52-100, aluminum, bronze, K-Monel, and ceramics. This type of bearing can be either a full complement or retainer type. Two typical examples of thin-section bearings have the following measurements: (1) bore 110 mm., O.D. 140 mm., width 16 mm.; (2) bore 30 mm., O.D. 42 mm., width 7 mm. Address inquiries to Ann Arbor Bearing and Mfg. Co., 815 Wildt St., Ann Arbor, Mich.



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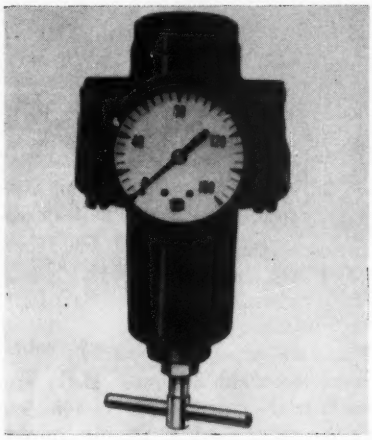

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Lube Lines

by A. F. Brewer*

Price — The Relation to Lubrication

"You get what you pay for" is a cliche among many serious buyers whether they are purchasing a few dollars worth of home conveniences, a new car or sponsoring a company expenditure of several hundred thousand dollars.

Price is an all-encompassing item — it includes among other things

(a) Cost of the raw materials.
(b) Cost of transporting them to the plant for processing to finished goods.
(c) Labor cost for this processing.
(d) Time value of the machinery used.
(e) Cost of handling in the plant.
(f) Cost of packaging for shipment and, subsequently
(g) Sales and advertising costs.

All this applies to lubricants as well as to other material goods. Oftentimes where the market is highly competitive, the background cost of lubricant production may be lost sight of by the purchaser. The tendency is to match cents per gallon or per pound instead of considering prospective lubricant performance as the primary objective.

Let us look at this matter of performance. In effect it includes

(a) Stability of the lubricant when subjected to operating conditions.
(b) Its protective ability when in service in the machine.
(c) Its reliability when used in long-time service as, for example, in pre-packed ball or roller bearings.

These are details with which management should be vitally concerned because a few more dollars spent for their assurance can mean operating insurance for machinery oftentimes worth several thousand times as much. Fortunately the lubrication engineer and the maintenance people realize this value. Fortunately some of them have an equally farsighted management. Others, however, must become salesmen in their own bailiwicks in order to broaden their management's viewpoint.

To some, price is often a mythical detail. It depends upon the commodity. It is ironic that the purchaser who goes for the flashiest car or possibly some other personal item which might be beyond his means, where his own money is concerned, will pinch pennies in the office. Maybe he feels company loyalty demands this procedure. Too often the company pays more in the long run, however, when some piece of mechanical equipment fails through use of an inferior lubricant and requires renewal of costly parts.

Where lubricants are involved the purchaser is buying more than simple commodities. Basically he is buying the means for promoting

(a) Dependable machine operation.
(b) Low cost maintenance.
(c) Insurance against fire, and
(d) Safety of plant personnel.

As a result he should look beyond the first cost figures and realize that he should be concerned chiefly with how the suggested lubricants will function in service. The comparative value of the cost of lubrication versus the cost of the machine is usually insignificant. Take a steam turbine for example. A few barrels of premium grade circulating oil fortified to protect against oxidation, rusting and foaming might cost well under a thousand dollars a year for make-up. Compare this with the cost of the turbine and the value of the labor, time and power loss should a bearing need replacement. Obviously it is folly to quibble over the cost of the oil per gallon when the resultant costs for repair and maintenance due to use of an unsuitable oil can be so alarmingly high.

Naturally management is concerned with the overall costs of materials used in the plant. Careful purchasing therefore, is encouraged and expected. But in consideration of the dollar value of lubricants in particular, one must not lose sight of the fact that this dollar value relates not only to gallons or pounds but, far more importantly, to the dependability and performance of the products.

*Consultant, and author of *Basic Lubrication Practice.*

New extreme-high-temperature lubricants for missiles and supersonic aircraft **SHELL ETR GREASES**

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LUBRICATION ENGINEERING

RESEARCH APPLICATION EDUCATION MAINTENANCE

Journal of the American Society of Lubrication Engineers *Vol. 14 No. 6 June 1958*

"Hard Times" Demand Maximum Efficiency

It is not necessary to turn to this page of this magazine to be informed of a fact now obvious to each of us — namely that we are in a type of recession that is completely different from any that our nation has ever experienced. Unemployment is up, corporate profits are down, consumer spending is down, but prices of goods and services stand at an all-time high. In April, the cost-of-living index showed a rise of 3½% over April of 1957.

By now it should be plain that no overnight miracle is going to clear up our nation's economic situation. In order to help provide for a readjustment — in order to have prices go down and consumer spending go up — industry must be able to effect the greatest possible economies in its purchases and its production in order to be able to market its commodities at the most attractive price.

How to help achieve these economies for industry lies squarely within the domain of the lubrication engineer. It is one of his functions to make certain that machines operate at highest efficiency. The savings which a trained lubrication engineer can offer management have been proven time and again.

Although lubrication problems differ with specific industries, many companies are finding that the services of a lubrication engineer pay off. His services can extend machine life, eliminate production losses, reduce rejects, simplify lubricant inventories and otherwise add to efficiency.

Take this example from industry: One firm reports that, by application of scientific lubrication principles, man-hours per unit of production were reduced 42% while lubrication costs were reduced 57% per unit with a corresponding 42% reduction in lubricants consumed. Further savings were effected through proper selection and volume buying of lubricants, resulting in lubricant cost increases of only 39% since 1940.

Proper lubrication and maintenance of machines cannot be practiced by just anybody. It takes a man skilled in the science of lubrication to make the proper choice as to which lubricant will operate at optimum efficiency. A company can effect all sorts of savings by cutting advertising, trimming its sales force, or minimizing its office help, but while these savings may look good on paper, they certainly do not keep production costs down.

It is time for all industry to take a good, hard look at the immediate problem. In this age of specialization, the lubrication engineer is a key man in keeping production costs down. Companies which are making use of his services recognize his effectiveness. Others are finding it increasingly difficult and increasingly costly to ignore him.

Calvert L. Willey,
Executive Secretary

Recovery of Used Cutting Oils:

Evaluation of Centrifugal Clarification

Alvin H. Lipton and Robert F. McKibben***

Material removed by centrifugal recovery equipment has been related to operating characteristics of screw machines. Resinous products, formed as the result of normal use of cutting oils, can seriously detract from satisfactory machine operation. Effective removal of resinous contaminants may be the most important factor to consider in large scale re-use of cutting oils.

Used oils, particularly used cutting oils, are commonly subjected to one or more of several treatments as part of their re-use cycle. A popular type of processing is centrifugal clarification. One clarification system, based on a centrifugal separator, has been evaluated in relation to machine tool operating characteristics. Practical analysis of centrifuge cake yielded several materials which interfere with machine tool operation.

Cutting fluid users are concerned with both the machining properties and the operating characteristics of their fluids. The present study is concerned principally with operating characteristics of non-emulsifiable cutting oil after suitable machining properties have been attained.

The author's company requires a variety of both water-base and straight-oil cutting fluids to produce its large assortment of parts. Of this variety, one general-purpose straight-oil fluid, referred to within the company as screwcutting oil, is used on free-machining steel in sufficient volume to warrant centralized handling (Table 1). All work reported herein resulted from evaluation of clarification equipment handling screwcutting oil.

Treatment of used screwcutting oil started in 1929 as a settling operation. Four 500 gallon settling tanks in series retained used oil about four days. Clarified oil was withdrawn from the final tank, and settled material was periodically removed from the system by hand. Total usage was 500 gallons daily for one 8-hour shift because some machines, specially set-up for particular parts, were run only as the parts were required. At this time 15,000 gallons of screwcutting oil were in circulation of which 85 percent was in machine tool sumps and 15 percent was in the settling tanks.

TABLE 1. NEW SCREWCUTTING OIL

Viscosity (S.U.S. at 100°F)	175
Fat %	1.0
Sulfur %, Chlorine %, each	0.25
Neutralization Value (Acid)	0.01
ASTM Sludge (D-91) %	0.0

Increased production during World War II created needs for a throughput of about 3,000 gallons of screwcutting oil per day (Table 2), decreasing average settling time from four days to 16 hours. Filtration was installed to compensate for decreased settling time. Settled oil was passed through a corrugated-paper disc filter designed for edge-flow between the discs. A system was installed to permit more rapid filtration by heating used oil to 140°F. A back-wash operation each eight hours cleaned the filter.

Following a period of apparent satisfaction, screens in machine reservoirs began to clog with gummy deposits. Gum formation in oil was known to be accelerated by heat, therefore the heating system was shut off. The immediate consequence of cold filtration was to clog the filter every 15 minutes. Filtration was discontinued because of high cleaning requirements and interruption of oil supply.

A high-speed centrifugal separator was installed to treat the oil after it had passed through the settling tanks (8).† Two positive results were obtained within a month:

(a) Clogging of screens was eliminated.
(b) Erratic action (binding or sticking) caused by varnish deposits on machine ways was eliminated.

TABLE 2. CENTRAL SYSTEM CUTTING OIL

	1929	1940-43	1957
Machine Tools	600	650	800
Hrs./day (average)	8	24	22
Gallons of Oil (estimated)			
Machines	15,000	20,000	35,000
Recovery system	2,000	2,000	2,000
Daily usage	500	3,000	3,600

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**Section Head, Lubrication Laboratory, Finishes Control Laboratories, The National Cash Register Company, Dayton 9, Ohio.

†Numbers in parenthesis refer to bibliography at end of paper.

Two additional benefits were observed, but not quantitatively evaluated:

(a) Improved surface finish was noted.

(b) Longer tool life was achieved.

These improvements in machine tool operating characteristics indicated that the material removed from screwcutting oil by centrifugal clarification was responsible for the less-than-satisfactory operation experienced before its removal.

Centrifugal operation delivered all heavier-than-oil material as a cement-like caked mass. Centrifuge cake, removed after each eight-hour running period, was analyzed to determine the type and quantity of material responsible (by its absence) for the above improvements. The term "sludge" is used to identify the heavier-than-oil centrifuge cake, and, to avoid confusion, "ASTM Sludge" will denote results of such ASTM tests as D-91.

A simplified presentation of sludge analysis was chosen — first of methods, then of results (Table 3).

TABLE 3. SLUDGE ANALYSIS

Treatment		*Product*
Hydrocarbon Solvent Extract		"Sludge Oil"
Ester or Ketone Solvent Extract		Resin
HCl Reactive		Metals
Ashing	a. Loss	Combustibles
Ashing	b. Residue	Abrasives
Remainder		Water

TABLE 4. DIRECT-ACTING CONTAMINANTS

Material	*Effect*
Resin	Binding Erratic action Clogged screens
Abrasives	Poor surface finish
Metals	Act as abrasives; lower tool life
Combustibles	Accumulate to clog supply lines

ANALYSIS

Sludge Oil

Sludge is macerated with a hydrocarbon solvent, such as petroleum ether, to reduce the cake to fine particles. The sample is treated with several portions of petroleum ether to extract all soluble material. Each portion of solvent is removed by decantation; the decanted portions are combined, then all solvent is removed by evaporation to produce an oily product called "sludge oil." Extraction with petroleum ether is continued until the decanted liquid is water-white, indicating complete removal of matter soluble in this solvent.

Resin

All material insoluble in petroleum ether is extracted with an equivalent of lacquer thinner. Butyl acetate was standardized on, but any ester or ketone solvent of convenient handling characteristics would suit the purpose. The extraction procedure is the same as that described under "sludge oil." In this case, however, a brown, hard, brittle material remains after evaporation of the solvent. The brittle product is called "sludge resin," or simply "resin."

Metals

After both solvent extractions are completed, the remaining insoluble portion is dried, then treated with concentrated hydrochloric acid until reaction is complete. Residue from HCl treatment is removed by filtration. Weight loss is defined to be "metals."

Combustibles and Abrasives

The dried residue remaining after HCl treatment is ashed at 1200°F. Loss in weight during ashing is called "combustibles," and the residue is called "abrasives." Combustibles consists of paper, wood, lint, and casual factory dust. "Abrasives" describes silica, the predominating material found in the residue from the ashing process.

Water

As an analytical expedient, water in sludge is arbitrarily defined as the difference between 100 percent and the total analytical results described above. The arbitrary definition has produced water percentages which agree (within ½ percent) with water determinations (ASTM D-95) on sludge "as received."

Water removal has been virtually complete in our centrifugal clarification. Moisture-free cutting oils have been claimed to be bacteriostatic(1), and our experience with clarified oil has thus far confirmed this opinion.

Figure 1 shows the average results of sludge analysis. All the sludge components can effect either machining or machine tool operation. Ingredients of sludge have been broadly classified into two groups of contaminants with respect to machining and machine operation, direct-acting and indirect-acting.

Direct-acting sludge ingredients (Table 4) can immediately interfere with machining. Resin, metals, combustibles, and abrasives comprise this group. Resinous deposits on machine ways cause erratic, hesitant action. Resin is also an excellent binder for chips and dirt, forming a cement-like mass which clogs machine screens. Abrasive particles, delivered with used oil, act at the toolwork interface to reduce tool life and produce unsatisfactory finishes. Combustibles, such as wood, lint, and

Figure 1. Sludge and its components.

paper can restrict the prescribed flow of cutting fluid by clogging supply lines and valves, but this has not been a major problem. Metals are primarily indirect-acting contaminants, but they are also listed in the first group because some abrasive action and poor finish can result from their presence.

Indirect-acting contaminants (Table 5) are those portions of sludge which tend to promote resin formation by oxidation or polymerization processes. The combination of water and metal in oil is a well-known means of promoting oil degradation, used, for example in ASTM D-943 (turbine oil oxidation). Sludge oil is a concentrated source of raw material for additional quantities of resin, as is shown in Table 6.

Sludge oil, resin, and the used oil from which they were removed, were compared for relative unsaturation, as measured by bromine number.‡ Used oil exhibited only half the degree of unsaturation of sludge oil, but the resin was roughly equivalent to used oil in degree of unsaturation. Oil breakdown seems to be accompanied by the formation of unsaturated compounds (sludge oil) which then interact, by either an oxidation or polymerization mechanism, to form a more saturated material (resin). Whatever the explanation, sludge, as removed by the centrifugal separator, contains appreciable amounts of what may be referred to as "resin-forming" material.

One of the most important benefits which has been derived from centrifugal clarification is the removal of sludge oil. Sludge oil is considered the sludge component most ready to become resin on its return to a machine tool cutting oil system. Effective removal of both resin *and* sludge oil will provide a recovered cutting oil comparable to new cutting oil, with respect to percentage of resinous materials. Should either or both the sludge oil and resin remain in used oil, they will deposit out either *when* their solubility limit is reached or *where* stagnant pools of cutting oil accumulate.

Periodic determinations have been made of the ASTM sludge content of used screwcutting oil by Method D-91 (Table 7). Results indicate an average removal of 95 percent of the sludge was effected by centrifugal clarification.

Sludge analysis and the total ASTM sludge determinations have been related on the basis of the total volume of screwcutting oil in our machine tools. An overall picture of centrifugal clarification effectiveness presents itself, first as a total of contaminants, (Table 8), and second as related to a 6 spindle, 9/16 in. Acme-Gridley running on 90 gallons of cutting oil (Table 9).

TABLE 5. INDIRECT-ACTING CONTAMINANTS

Material	*Effect*
Metals	Oxidation catalyst (drier)
Water	Oxidation promoter Bacterial agent
Sludge Oil	Oxidizes to resin

TABLE 6. UNSATURATION CHARACTERISTICS

	Used Oil	*Sludge Oil*	*Resin*
Total Acid No.	2.4	13.6	17.4
Bromine No.	6.6	12.4	6.3

‡Unsaturation is greater as bromine number increases.

TABLE 7.
SCREWCUTTING OIL AVERAGE SLUDGE CONTENT

	ASTM Sludge % (D-91)
New	0.0
Used (before centrifuging)	1.0
Used (after centrifuging)	0.05

TABLE 8. CUTTING OIL CONTAMINANTS
(35,000 gal in 800 machines)

	Before Centrifugal	*After Clarification*
Sludge Oil	2278	114
Resin	3038	152
Metals	1519	76
Combustibles	304	15
Abrasives	228	11.5
Water	228	11.5
Total Sludge (Sp. Gr. = 2.6)	7595 lb	380 lb

TABLE 9. CUTTING OIL CONTAMINANTS
(Basis: 90 gal cutting oil per 9/16 in. Acme-Gridley)

	Before Centrifugal	*After Clarification*
Sludge Oil	5.6	0.28
Resin	7.6	0.38
Metals	3.8	0.19
Combustibles	0.8	0.04
Abrasives	0.6	0.03
Water	0.6	0.03
Total Sludge	19.0 lb.	0.95 lb.

SUMMARY

Recovery of used cutting oil should consider two functions of the oil—machining and operation. Resinous contaminants, which detract from operating properties, are more readily removed by centrifugal clarification than by filtration. Centrifugal processing has been found to effectively remove resinous contaminants in addition to its better-known function of removing metals, abrasives, and water. Operating quality of centrifugally-recovered cutting oils has been found equal to that of new cutting oil, as judged by machine tool operating characteristics.

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Friction of Polytetrafluoroethylene Dry Bearings

*S. B. Twiss, P. J. Willson and E. J. Sydor**

Experiments designed to simulate bearing performance were conducted on a number of compositions containing polytetrafluoroethylene (PTFE). Two basic types of materials were investigated: PTFE reinforced with additives (PTFE-bonded) and molded products of phenolic resins, PTFE and fillers (resin-bonded). Friction test variables were speed, load and temperature — the ranges covered were 6 to 625 fpm, 30 to 250 psi, and room temperature to 300°F, respectively. It is shown for both types of materials that the coefficient of friction is inversely related to the amount of PTFE present. For a resin-bonded material the coefficient of friction varies inversely as the surface roughness of the steel mating part. Hardness and compressive strength measurements on resin-bonded materials show that these are also inversely related to the amount of PTFE present. Preliminary bearing tests showed that the resin-bonded compositions possess desirable friction characteristics and resistance to cold flow.

INTRODUCTION

Polytetrafluoroethylene (PTFE) is a relatively new engineering material possessing several unique properties which make its use as a bearing material of interest. Foremost among these properties is its relatively low coefficient of friction when run unlubricated. The frictional characteristics of compounded PTFE and methods for overcoming some of its structural weaknesses by compounding will be discussed in this article.

Previous investigators have reported a range of values for the coefficient of friction (f) of PTFE, which we believe can be attributed partially to differences in test conditions. Shooter and Thomas (1)[1], using a Bowden-Leben test apparatus, reported an f value for PTFE sliding on steel of 0.04 when the range of sliding speeds, loads and temperatures were approximately 0.02 to 2 ft/min, 2 to 9 lb and 68° to 392°F, respectively.[2] In a later experiment, Shooter (2) reported a coefficient of friction of approximately 0.1 when the normal load was 22 lb and the speed less than 2 ft/min.

Bowers, Clinton and Zisman (3), using a Bowden-Leben type machine, reproduced Shooter and Thomas' value of 0.04 under the same test conditions. They further reported that when a steel rider traveled over heat polished PTFE, the friction increased to about 0.15.

White (4) observed the frictional behavior of PTFE in a journal bearing application; f was in the range of 0.20 to 0.27. Thompson, Turrell and Sandt (5), using a micropolished steel ring riding on a constrained ring of PTFE at very high loads, reported very low coefficients of friction, of the order of 0.016 to 0.029.

Flom and Porile (6) reported that the coefficient of friction of PTFE on PTFE is dependent upon the conditions of the wear track as well as the speed of sliding for stationary pin and rotating cylinder specimens. The f value was 0.05 to 0.08 on an *unworn* track at low speed and load, but rose to 0.19 for a *worn* track. Increasing the speed caused the coefficient to rise to the range of 0.32 to 0.36.

Unlubricated PTFE parts have found their way into many engineering applications. Pure PTFE, however, has many properties which prevent its universal acceptance as a general purpose bearing material. Among its deficiencies are low hardness and compressive strength, low resistance to deformation under load, high wear rate, high molding temperature, and high cost. One method that has been used to overcome these weaknesses is the incorporation of solid fillers with PTFE powder to form an improved molded product (7). A new approach proposed by the authors was a composite bearing material containing a relatively hard resin matrix for strength and PTFE particles interspersed within the matrix to give a low coefficient of friction. It was expected that, in addition to marked improvement in physical properties, lowered cost would result from the use of conventional resin mixing and molding techniques The frictional behavior of both types of molded products will be discussed later, i.e., [(a)] the sintered product of PTFE and solid additives (PTFE-bonded), and [(b)] the molded product of resin and PTFE (resin-bonded).

EXPERIMENTAL

Composition

The main ingredients of the *resin-bonded* bearing materials consisted of a resinous binder, a dry lubricant (PTFE) and a reinforcing filler. In some cases, powdered fillers (non-reinforcing) were used to obtain special properties. Although many compositions were fabricated where the type of binder was varied, the compositions discussed in this paper were restricted to the phenolic type

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[1]Numbers in parenthesis refer to references at end of article.

[2]For a more rapid comparison with the results obtained in this laboratory, we have taken the liberty of converting all metric units to the approximate engineering equivalent in references (1, 2, 3, 4, 5 and 6).

resins. Typical formulations are summarized in Table 3 in the Appendix, which also gives details of mixing and forming of the molded bearings.

Nineteen *PTFE-bonded* compositions were obtained from a commercial source. These compositions included nine different reinforcing fillers, representing a wide range of materials and present in varying amounts. Their composition is shown in Table 4 of the Appendix, where mixing, forming and sintering details are also included. The friction properties of all compositions were investigated, but space allows only a selected group to be discussed in subsequent sections.

Test Procedures

The friction measurements were made on an apparatus designed and built in the authors' laboratory (8). Measurements were carried out using a ½ in^2 sample which was pressed against a rotating steel disk with a normal surface finish of 3 to 6 microinches. Figure 1 is a schematic diagram of the load and friction forces involved in the measurement. The friction apparatus is highly instrumented to allow for controlled heating of the disk up to 1000°F, controlling speed from 6 to 1500 fpm, and varying the dead weight load from 10 to 250 lb (20 to 500 psi). As indicated in Figure 1, friction force is measured by use of a bonded wire resistance strain gauge. The test consisted of four parts:

Part 1 — Run-in: 30 min, 25 fpm, 150 psi, room temperature.

Part 2 — Temperature test: 25 fpm, 150 psi, 5°F per min temperature rise, room temperature to 300°F, then cooled below 150°F.

Part 3 — Speed test: 150 psi, 150°F max., 6-625 fpm in seven stages, 100 sec at each speed.

Part 4 — Load test: 25 fpm, 150°F max., 30-250 psi in nine stages, 5 min at each load.

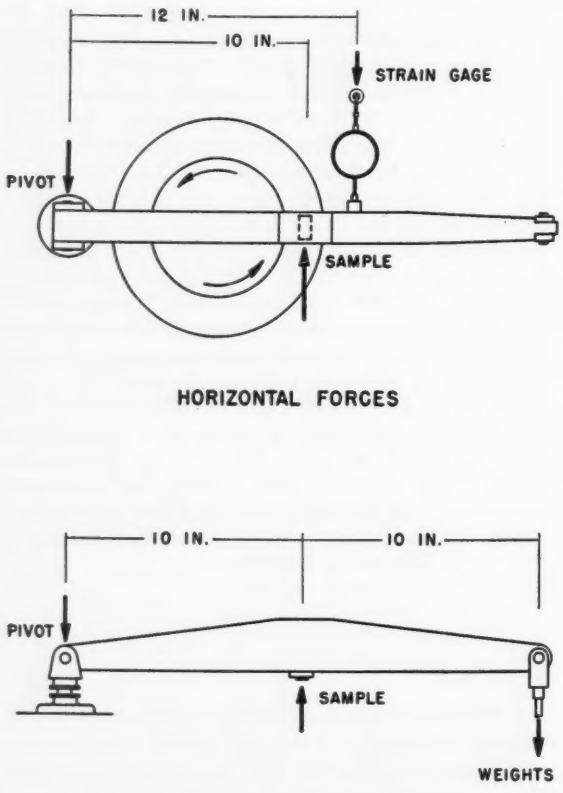

Figure 1. Force diagram of friction measuring apparatus.

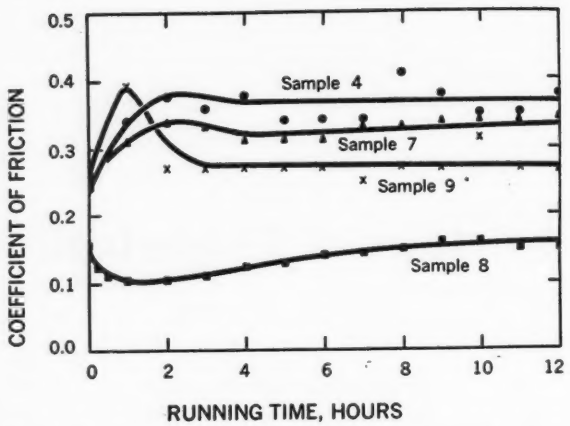

Figure 2. Effect of running on friction of resin-bonded compositions.

The tests were carried out in the order indicated above.

Selected physical measurements were performed on the samples to characterize the materials and determine what effect various additives or compounding techniques had on physical properties. These tests were hardness, compressive strength, water stability, hot oil immersion, and thermal expansion. A description of the test methods used and the results is given in the Appendix.

FRICTION TEST RESULTS

Resin-Bonded Compositions

Figure 2 shows the changes in friction which occurred during extended running. The data were obtained at a rubbing speed of 350 fpm and a load of 110 psi. There is little difference in friction among the samples containing asbestos fillers and 20, 30 and 40 volume percent PTFE. We believe that the markedly lower friction for Composition 8 can be attributed to the presence of a powdered lead filler. Generally, the friction reached a stabilized value within the first two or three hours of running. The temperature observed during this test was proportional to the friction, ranging from 200°F for the lowest friction to 330°F for the highest.

The primary purpose of this investigation was to determine frictional behavior of various compositions. However, to be useful as a dry lubricant bearing, these compositions would have to be at least as wear resistant as currently used dry lubricant bearing materials. It was found that our standard test did not yield measurable wear; therefore, extended tests were made on a few samples.

Table 1 shows the average wear rate for the most promising bearing materials when subjected to extended running periods of four to 12 hours at 350 fpm and under a load of 110 psi. From the results, it is apparent that there is little difference among the resin-bonded structures, but it can be seen that such a structure will

TABLE 1. WEAR RATES OF RESIN-BONDED STRUCTURES

Amounts of PTFE	*Wear Rate mils/hour*
Pure PTFE	69
40 Volume %	3
30 Volume %	5
20 Volume %	4

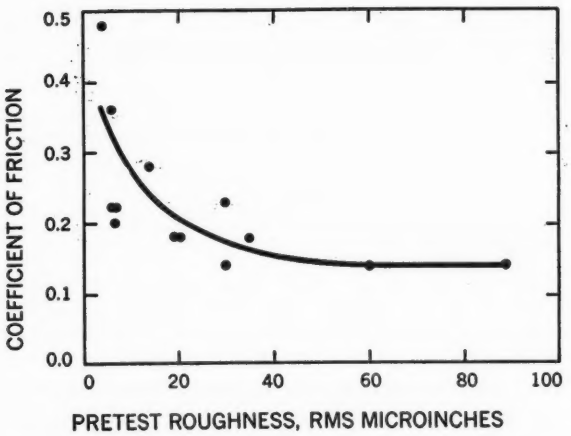

Figure 3. Effect of steel surface roughness on friction of a resin-bonded composition.

lower the wear rate by a factor of about 15 when compared to pure PTFE.

In order to completely evaluate a material and test procedure, it is important to investigate all of the variables which might affect test results. Figure 3 shows the effect of steel disk roughness on the friction of Composition 10, a resin-bonded material with cellulosic filler. The friction data were obtained at a temperature of 150°F max., a load of 200 psi, and a rubbing speed of 25 fpm. The trend toward lower friction at greater roughness is quite obvious. We have no explanation for the scatter of the results for samples run against the smoother surfaces. The reason for the lower friction on the rough surfaces may be that a layer of PTFE was transferred to the metal disk and held so that, in effect, PTFE was rubbing on PTFE. Various authors have reported lower friction for this situation (1, 3).

The dry lubricant properties of PTFE are clearly shown by the graph in Figure 4, which illustrates the effect of PTFE concentration on coefficient of friction. The data were obtained at 25 fpm, 200 psi and 150°F max., during the fourth part (Load) of the friction test.

TABLE 2. FRICTIONAL BEHAVIOR OF DRY LUBRICANTS

Material	*Coefficient of Friction*
Graphite Filled Phenolic Laminate	0.7 [a]
Dense Wood (Lignum Vitae)	0.7 [a]
Polyethylene	0.6 [b]
Nylon	0.52
Processed Graphite Composition	0.33
Soap Impregnated Woven Cotton	0.33 [c]
PTFE	0.21

[a] Incomplete test due to high friction results.
[b] Incomplete test due to rapid sample wear.
[c] Tested only for third part of friction test cycle.

The plot of coefficient of friction vs. volume percent of PTFE yields a smooth curve. The friction drops rapidly with increasing additions of PTFE and then levels off at a value just below 0.2.

The materials chosen to illustrate the effect of temperature, load and speed further illustrate the dependence of friction on PTFE content. Figure 5 shows the effect of temperature on the coefficient of friction of resin-

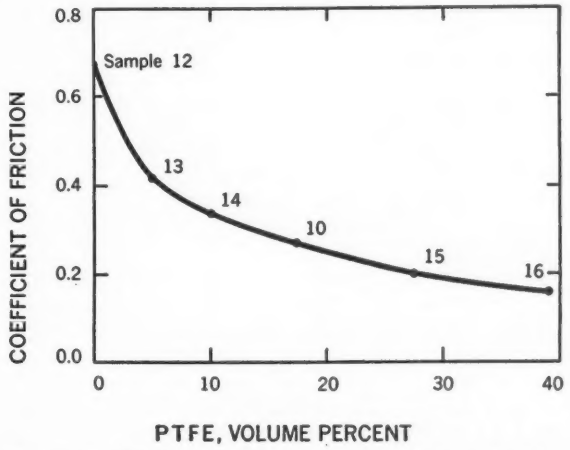

Figure 4. Effect of PTFE content on friction of resin-bonded compositions.

bonded materials. The data were obtained at 25 fpm and 150 psi during the second part (Temperature) of the friction cycle. The samples represented by the curves labeled 12 through 16 contained, respectively, 0, 5, 10, 27 and 39 volume percent of PTFE (see Table 3). As can be seen, temperature has little effect on Compositions 12, 15, 16 and a somewhat variable effect on the intermediate Compositions 13 and 14. The content of PTFE is by far the more important variable.

The resin-bonded samples previously described which contained various amounts of PTFE were tested at 150 psi and 150°F max. for 100 seconds at each of seven speeds. The results are shown in Figure 6 for the third (Speed) part of the friction cycle. The tests were run for 100 seconds at each speed to minimize the effect of temperature generated by friction. The effect of speed

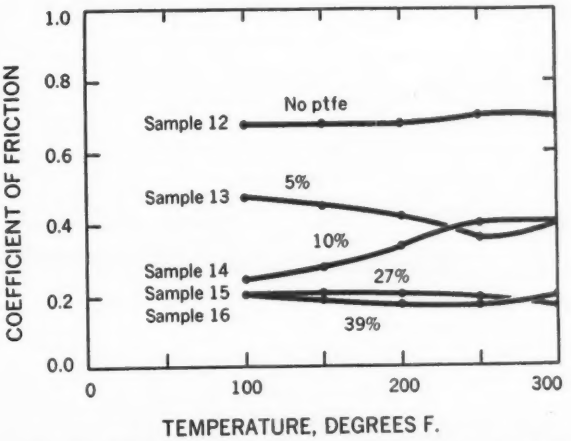

Figure 5. Effect of temperature on friction of resin-bonded materials.

TABLE 3. COMPOSITION OF RESIN-BONDED MATERIALS

Three-Component System:
PTFE: TF-1
(Coarse, general purpose PTFE particles)
Resin: Phenolic Type
Filler: Variable

		Volume Percent			*Weight Percent*		
Sample	*Filler*	*PTFE*	*Resin*	*Filler*	*PTFE*	*Resin*	*Filler*
4	Asbestos	20	30	50	21	17	62
5	Aluminum Oxide	37	31	32	33	17	50
6	Asbestos	17	31	52	18	19	63
7	Asbestos	40	22	38	41	13	46
8	Lead, Powdered	37	31	32	16	8	76
9	Asbestos	30	26	44	31	16	53
10	Cellulose, Alpha	17	31	52	25	25	50
11	Wollastonite	17	31	52	17	17	66
12	Cellulose, Alpha	0	37	63	0	34	66
13	Cellulose, Alpha	5	35	60	8	32	61
14	Cellulose, Alpha	10	34	57	15	29	56
15	Cellulose, Alpha	27	27	46	37	22	42
16	Cellulose, Alpha	39	23	39	50	17	33

is apparently greatest for the resin-bonded sample containing no PTFE, and least for the samples containing relatively large amounts of PTFE (Samples 15 and 16). The marked drop in friction for Sample 12 is probably due to surface temperature rise in spite of the precautions taken to maintain the disk temperature below 150°F. Over this speed range, the effect of low speed operation on coefficient of friction is not clear. Other tests have shown that at speeds below a few feet per minute the friction of compositions with high PTFE content does drop to a lower value than represented by high speed dynamic values. Again, these results indicate the overriding effect of PTFE content on the level of friction.

The effect of load on friction is shown in Figure 7. The test conditions are 25 fpm, 150°F max., five minutes running at each load, from the fourth part (Load) of the friction test cycle. The samples were the same as those

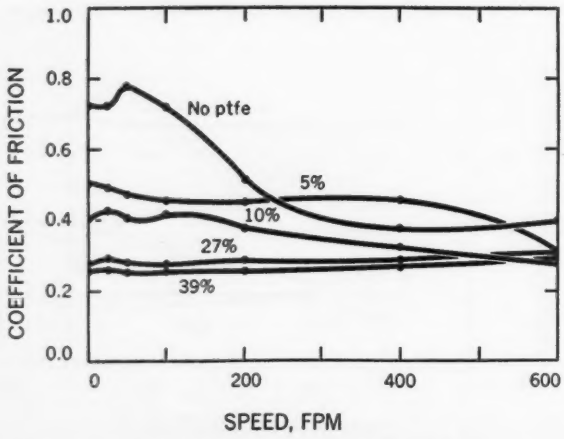

Figure 6. Effect of speed on friction of resin-bonded materials.

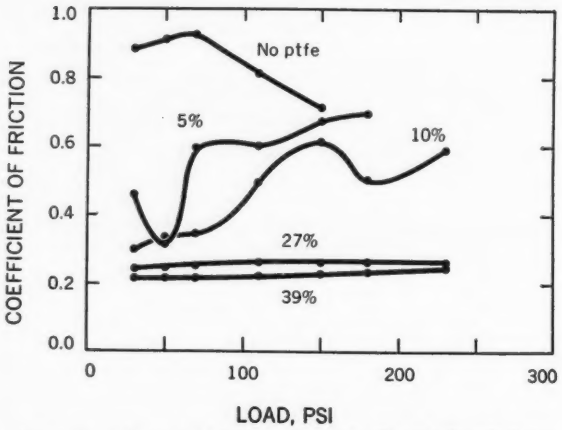

Figure 7. Effect of load on friction of resin-bonded materials.

discussed previously, which had various amounts of PTFE from 0 to 39 volume percent. It can be seen that when sufficient PTFE is present, the friction is low and stable. Lesser amounts of PTFE produce variable friction, which is probably due to competition between the phenolic resin and PTFE for sites on the rubbing surface. It is obvious from the results shown here and previously for the sample containing no PTFE that phenolic resin produces a very high friction coefficient. For the samples containing intermediate amounts of PTFE, increasing load appears to favor transfer of phenolic resin, with a resultant increase in friction at higher loads.

PTFE-Bonded Compositions

Figure 8 gives an indication of the effect of filler concentration and type on friction, averaged over a temperature and load range at a speed of 25 fpm. As expected, the PTFE concentration primarily controls the friction. It is very interesting to note, however, that no filled or reinforced samples exhibited a friction lower than that of pure PTFE. It appears that filler type may affect the friction results, but no consistent trend was noted. This is contrary to the conclusion arrived at by Thompson, et al (5) who investigated high load, low speed friction of reinforced PTFE containing different fillers in amounts up to 32 volume percent. It should be noted that, under the conditions of our experiments, the coefficient of friction was much higher and filler contents up to 75

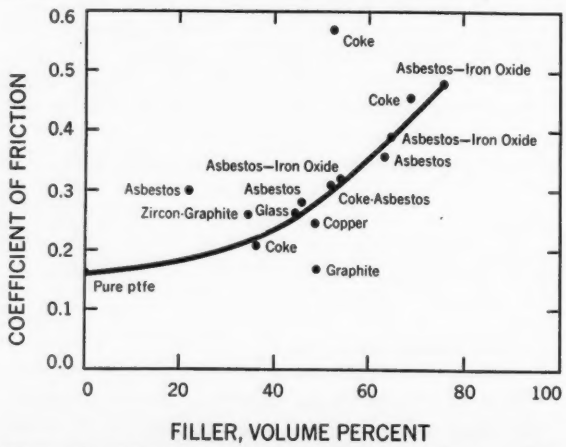

Figure 8. Effect of filler concentration and type on friction of PTFE-bonded compositions.

TABLE 4. COMPOSITIONS OF PTFE-BONDED MATERIALS

Sample	Filler	Volume Percent PTFE	Volume Percent Filler	Weight Percent PTFE	Weight Percent Filler
A	Asbestos	46	49	40	50
	Fe_2O_3		5		10
B	Coke Flour	47	53	50	50
C	Coke Flour	48	44	50	40
	Asbestos		8		10
D	Asbestos	54	46	50	50
E	MoS_2	69	31	50	50
F	Asbestos	24	71	20	70
	Fe_2O_3		5		10
G	Asbestos	35	60	30	60
	Fe_2O_3		5		10
H	Coke Flour	31	69	33	67
I	Asbestos	37	63	33	67
J	Zircon Flour	65	25	50	42
	Graphite		10		8
K	Mg-Al Alloy	32	68	33	67
L	Graphite	51	49	50	50
M	Coke Flour	64	36	67	33
N	Copper	51	49	20	80
O	Asbestos	78	22	75	25
P	Glass Fiber	56	44	50	50

volume percent were used. It is apparent that amount of filler is a more important factor than the type of filler.

The samples selected to illustrate the effect of temperature, speed and load all contain about fifty volume percent of PTFE (see Table IV). In Figure 9 the effect of temperature is illustrated. The effect shown appears to be primarily due to the effect of temperature on the fillers. Samples "A" and "D" which contained asbestos exhibit increasing friction with temperature. A similar effect has been observed for pure asbestos[3] where friction increases from 0.55 at 100°F to 0.64 at 300°F. Materials "C" and "B" were very similar in composition, except that "C" contained 8 percent asbestos. It is understandable that these two compositions should exhibit the same friction, and the same effect of temperature, except at the highest temperature, 300°F, where "C" is slightly higher. Composition E, containing molybdenum disulfide as filler, shows the surprising result that an otherwise excellent dry lubricant does not lower the friction of PTFE with coke flour filler.

Figure 10 shows the effect of speed on the same five materials discussed above. The effect of speed on friction

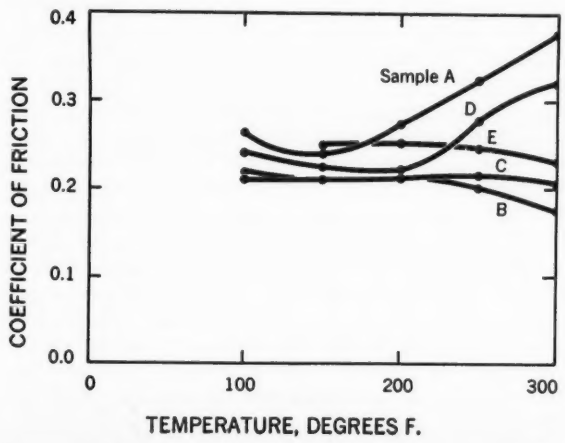

Figure 9. Effect of temperature on friction of PTFE-bonded materials.

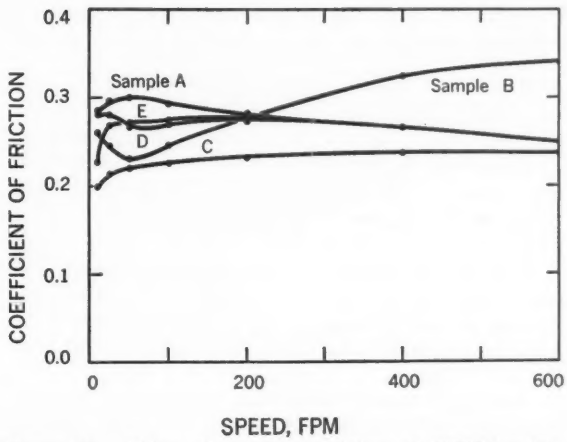

Figure 10. Effect of speed on friction of PTFE-bonded materials.

appears to be minor, except for Sample "B" which seems abnormal, but has been confirmed by duplicate tests. The low friction at low speeds, which has been observed by other investigators (6), (9), appears to be a fundamental characteristic of PTFE. This property is also of considerable importance in the use of PTFE in plastic bearings, resulting generally in the absence of stick-slip friction and noise. The increase in friction of Sample B is an anomaly which apparently has not been observed by other investigators.

The effect of load on the friction of the same PTFE-bonded materials is shown in Figure 11. It is evident that within this load range the effect of increasing load is slight to variable. No explanation is known for the change in friction of B, while C which also contained coke flour does not change. This result is not entirely consistent with other work on filled PTFE reported in the literature. Thompson, et al (5), found that with pure PTFE in the load range of 400 to 3600 lb, the friction coefficient dropped to a very low limiting value of less than 0.02. Milz and Sargent (9), using crossed cylinder specimens, found that for filled PTFE compositions the friction coefficient decreased slightly (from about 0.20 to 0.15) with increased load. It is probable that the effect of load on friction does not become apparent unless extremes of load range are used. It is also possible that

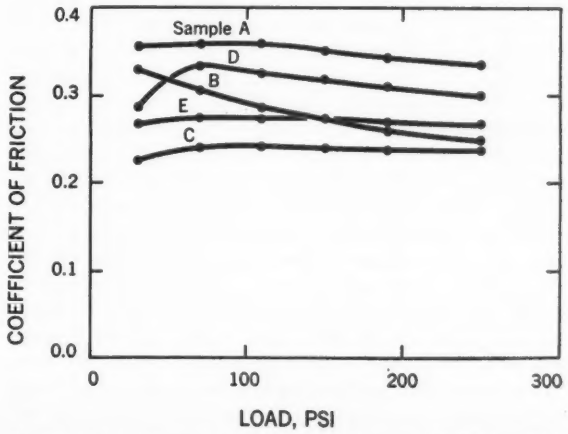

Figure 11. Effect of load on friction of PTFE-bonded materials.

certain fillers might function to upset the normal decrease of friction with load, at least over part of the load range.

Comparison of PTFE with Other Lubricants

A comparative test was performed on some of the other most widely used non-lubricated bearing materials. The results were obtained at a temperature of 150°F max., a load of 200 psi, and rubbing speed of 25 fpm, during the fourth part of the friction test cycle. These results are shown in Table II.

It is not our intention to suggest that the non-PTFE bearing materials are useless in unlubricated applications. Our type of test is known to be exceedingly severe; all of the above have performed satisfactorily under less rigorous conditions of selected industrial applications.

The qualitative effects of other dry lubricants as substitutes for PTFE in the resin-bonded compositions were observed. We found that a complete volume substitution of PTFE by polytrifluorochloroethylene, calcium stearate, molybdenum disulfide and graphite in a resin-bonded structure (Composition 10) increased the coefficient of friction above that normally observed. The increase in the frictional value in the chlorine substituted polytetrafluoroethylene is not surprising in view of the work performed by FitzSimmons and Zisman (10).

Effect of Fillers

We believe that certain filler ingredients may have a significant effect on the frictional properties as well as modifying the physical properties. In the extreme case, we found that a finely divided aluminum oxide filler (Composition 5) yielded friction values more than three times higher than when a finely divided powdered lead (Composition 8) was used in resin-bonded, PTFE-containing bearings. One possible explanation is that the hard aluminum oxide particles plow through the otherwise continuous film of transferred PTFE, thus increasing the frictional value. Further, if the PTFE film is thin enough, it may be that the film is completely penetrated and thus limited contact with the metal can be effected. This picture, then, is not unlike boundary conditions observed in oil lubricated metal bearing systems.

RESULTS OF PERFORMANCE TESTS

Several of these compositions have been installed in applications that can be considered field tests. For instance, a bearing was installed in a housing supporting a one-inch shaft rotating at about 650 rpm. The shaft loading could be varied and provisions were made for measuring the torque developed. To provide a measure of the performance, the usual *PV* factor was used. This is the product of the unit loading on the projected area of the bearing surface in terms of pounds per square inch and the shaft rubbing speed in terms of feet per minute. At *PV* factors below 5000, satisfactory performance could be achieved with an equilibrium coefficient of friction of about 0.2. As heavier loads were applied, the temperature of the system rose. When a *PV* factor of 15,000 was reached, the temperature of the bearing housing was slightly over 300°F and seizure of the bearing occurred. Since this seizure was caused by the differential expansion of the bearing system, it was found that the temperature ceiling could be raised by increasing the running clearance at room temperature.

Another interesting application was that of a troublesome wear plate in a control linkage life test fixture. In operation, a lightly loaded ¼-inch chrome plated arm rubbed back and forth on the wear plate. The maximum speed of travel was about 20 fpm and the normal load was about 10 lb. Graphite filled, phenolic-duck laminates showed excessive wear after about 50,000 cycles, even when grease lubricated. A resin-bonded composition containing PTFE withstood over 500,000 cycles with very little evidence of wear.

Bushings and thrust washers of resin-bonded PTFE with an alpha-cellulose filler were installed in the kingpin assembly of an automobile. They replaced lubricated ball bearings and bronze bushings. Initially, the steering effort with the experimental parts in place was satisfactory, but after running in wet weather, the effort increased. Subsequent laboratory tests showed that the hydrophilic properties of the filler were responsible. New resin-bonded parts with an asbestos filler were installed and the water sensitivity problems eliminated. Subsequent running showed that the transferred film of PTFE was not an adequate means for the prevention of corrosion of the kingpin. The products of corrosion and the contamination due to road dirt caused the effort to increase with time.

SUMMARY

In summary, polytetrafluoroethylene (PTFE) shows interesting frictional characteristics for dry bearing applications, even though the values for coefficient of friction at the higher speeds of such applications are not as low as reported in the literature for low-speed running. The well-recognized deficiencies of PTFE, high wear and low compressive strength (or tendency to cold flow), can be partially overcome in either of two ways: (a) by the use of reinforcing fillers for PTFE, and (b) by incorporating PTFE as dispersed particles in a resin-bonded composition. The use of reinforcing fillers for PTFE (which is not a new technique) results in higher coefficients of friction, proportional to the filler content. The use of reinforcing fillers does not overcome a third deficiency of PTFE, namely, the high temperatures and specialized sintering techniques required to form such parts, with attendant health hazards. The new method of handling PTFE in bearing parts, by dispersing discrete particles of PTFE in a resin matrix, with or without reinforcing fillers, has several advantages. With sufficiently high PTFE content, 27 to 39 volume percent, the coefficient of friction of resin-bonded compositions is comparable to that of reinforced PTFE compositions. The wide choice available for secondary fillers in the same resin-bonded composition allows a range of physical properties not otherwise possible in PTFE-containing bearings. For example, compositions containing asbestos as a secondary filler have compressive strengths up to 18,000 psi. Resin-bonded compositions containing powdered lead as a secondary filler have extremely low friction, although compressive strength of such compositions is not exceptional. Finally, the resin-bonded materials can be molded at temperatures and pressures comparable to phenolic molding powders, with none of the health hazards associated with the sintering of PTFE. Resin-bonded compositions should be lower in cost.

Preliminary tests with the resin-bonded, PTFE- containing materials in bearing applications have been prom-

ising. The low coefficient of friction and improved compressive strength should widen the possible range of dry bearing applications. Work should be undertaken to:

(a) Improve heat transfer across the plastic bearing to maintain lower temperatures at high speed, and

(b) Find ways of preventing corrosion and wear of dry bearings which are exposed to moisture and road dirt.

ACKNOWLEDGMENTS

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APPENDIX

Composition

Resin-Bonded

Typical formulations of these materials are summarized in Table 3. Two mixing methods were used to fabricate the bearings discussed in this paper. These are: (a) A resin solution was prepared with the proper solvents and intimate mixing of PTFE particles and fillers carried out in a sigma-bladed mixer. After evaporation of the solvent, the mass could be powdered by conventional methods to form a molding powder. (b) The dry ingredients were dry mixed and then pulverized to the consistency of the molding powder.

Forming of the bearing parts was carried out as follows: The correct weight of powdered materials was charged into a compression mold and molded at 360°F for 20 minutes under a pressure of 8,000 psi.

PTFE-Bonded

The commercially-obtained PTFE-bonded compositions which were studied in this work are listed in Table 4. Sample K containing Mg-Al alloy ignited at the start of the friction test so further work on this sample was discontinued. There are three methods available for intimately mixing the PTFE particles with the additives, but the coagulation technique was used for preparing the samples investigated. The additives were mixed into the PTFE emulsion and then coagulated with the proper electrolyte. After drying the coagulant, the mass could be powdered by conventional methods to form a molding powder.

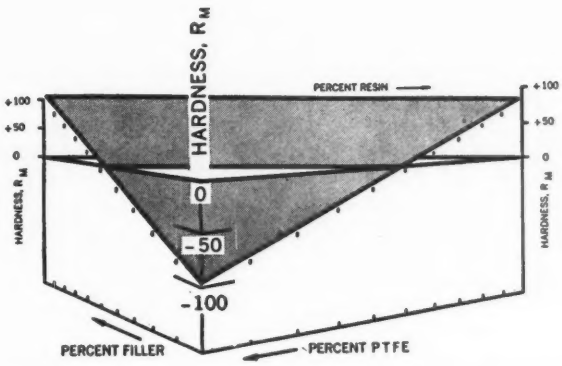


Figure 12. Hardness vs. composition of resin-bonded materials.

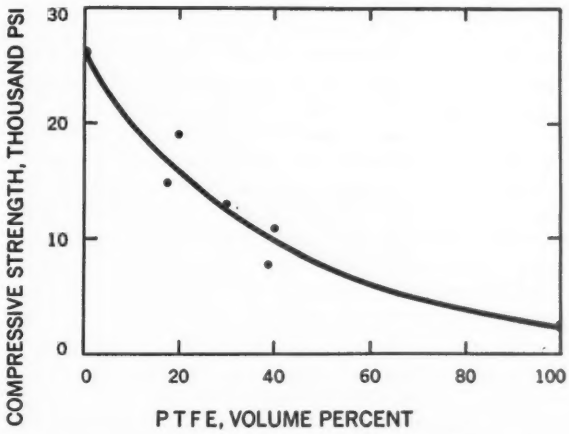


Figure 13. Axial compressive strength vs. PTFE content of fiber reinforced resin-bonded materials.

Bearing parts were formed by loading the powdered materials into a briquetting die and preforming them into simple shapes at room temperature under pressures of 2,000 to 10,000 psi. These preforms were then sintered at 700 to 740°F until the entire piece had reached the gel state and then cooled.

Physical Measurements

Certain physical measurements in addition to friction tests were carried out, primarily on the resin-bonded samples, to determine the effect of filler and PTFE concentration on the physical properties. The hardness values reported in this paper were obtained with a Rockwell Hardness Tester, Model H JR-PL using the "M" scale (ASTM D 785-51 Method). Figure 12 is a three-dimensional plot relating hardness to composition of resin-bonded materials. It can be seen that the hardness is determined predominantly by the PTFE concentration. The intercepts were all extrapolated from twenty points distributed over the area of the composition triangle. The dependence of hardness on PTFE content is further illustrated by the fact that the compositions represented contained different resins and different fillers, but in spite of this the trend to lower hardness at higher concentrations of PTFE is quite obvious.

The compressive strength measurements were made according to the ASTM D 695-54 method. Samples tested include Compositions 7, 9, 10 and 16, which contain alpha cellulose and asbestos fillers. The results showed that the resin-bonded materials exhibit anisotropic strength characteristics with weaker shear planes running perpendicular to the path of mold ram travel. Figure 13 illustrates the change of axial compressive strength with change in composition. The ratio of fibrous filler to binder is

(Cont. on p 273)

Lubrication Problems in Fabrication of Nuclear Reactor Metals

*by Paul Lowenstein**

INTRODUCTION

The complex requirements of nuclear power reactors have produced a demand for a number of metals not in common use. Although the properties of these materials are widely different in most respects, all have two characteristics in common: all of them are reactive materials, readily absorbing oxygen and other gases from the atmosphere at elevated temperature, and all of them present a problem in lubrication when attempts are made to work them plastically. They gall, stick or weld to tools under the conditions of friction and pressure which exist in all metal working operations.

The specific metals to be discussed here include two nuclear fuels, uranium and thorium; a reflector and moderator material, beryllium, and a low cross-section structural material, zirconium. These materials present some problems in cold working and additional problems, complicated by their reactivity, in hot working. In hot working, probably the most severe test of a lubricant is hot extrusion; in cold working operations, tube drawing presents the most severe application. These two fabrication steps will be used to illustrate fabrication problems for these materials and the types of lubrication techniques used to solve them.

In general, it is necessary to prevent all direct contact between these metals and the tools. Even one small area of contact between clean metal and tools results in the complete failure of the operation.

HOT WORKING

EXTRUSION:

In the hot extrusion of metals, a heated billet is placed in a cylindrical steel container, open at both ends. When pressure is applied to the billet at one end of the container, by means of a ram, the materials flow out at the other end and issue through an opening in the die. In the conventional extrusion, such as that for aluminum and copper, the flow occurs in a turbulent fashion (Fig. 1-a), with some of the metal from the center of the billet becoming the outside of the extruded rod. Under such conditions, it is obviously impossible to introduce a lubricant between die and metal. For the materials under discussion here it was necessary to develop methods which assured streamlined flow (Figs. 1-b and 2) in which the outer surface of the billet remains the outer

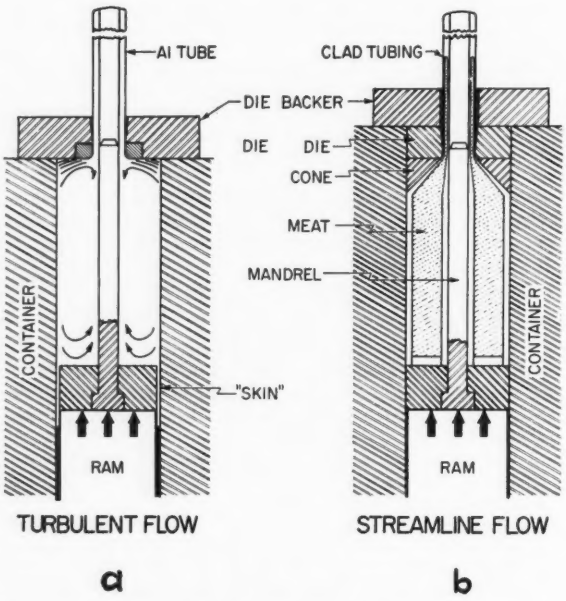


Figure 1. Turbulent and streamline flow.

surface of the extruded section and the only part of the metal in contact with the tools. To obtain this streamlining, several conditions are necessary:

1) The die has to be given a conical approach. Two methods of obtaining such an approach for round extrusions are illustrated in Figs. 3 and 4; a similar die for a flat section is illustrated in Fig. 5.

2) The extrusion ram exerting the necessary pressure on the billet has to be tight enough in the extrusion container to prevent back-extrusion, that is, the deposit of a skin or skull in the container, as in conventional extrusions.

3) The most important and most difficult requirement is to provide a lubricant which will flow with the metal and prevent contact with the tools.

From the early days of the Manhattan Project to the present, all possible conventional lubricants were tried without success. The first encouraging results were obtained when Gurinsky and Creutz (1)† placed a

*Nuclear Metals, Inc., Cambridge, Mass.

†Numbers in parenthesis refer to bibliography at end of article.

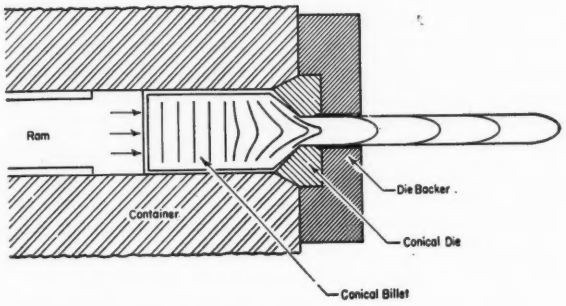


Figure 2. Streamlined flow.

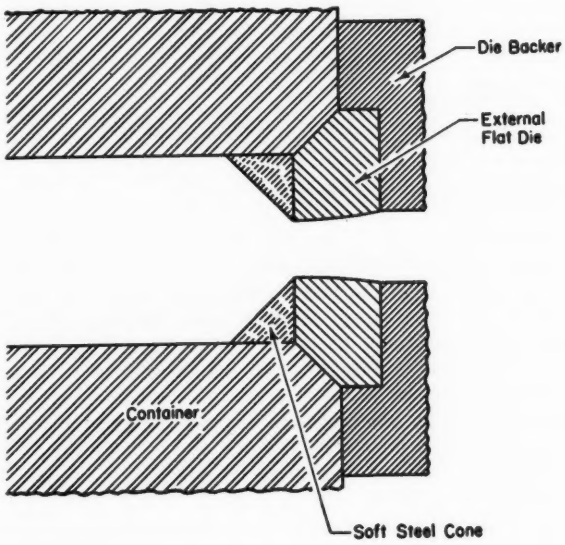


Figure 3. Internal flat die with a soft steel cone.

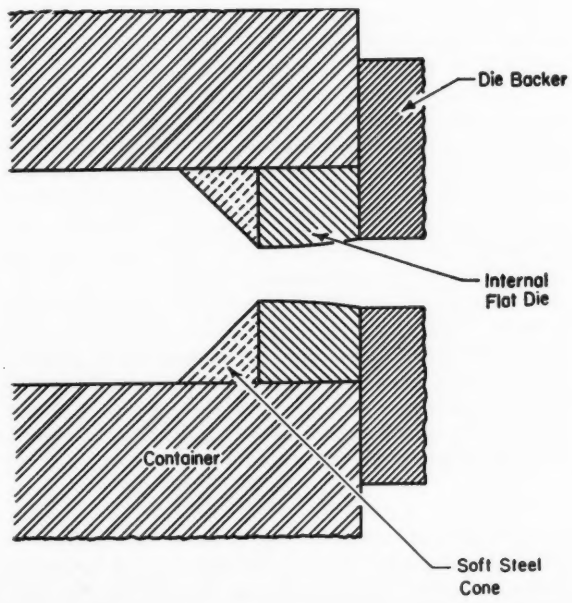


Figure 4. External flat die with a soft steel cone.

beryllium billet in an iron can and extruded the can with the beryllium. From this was developed a canning technique suitable to the four metals under discussion as well as to many other metals difficult to extrude.

Fig. 6 shows a typical billet and extrusion can. The metallic can has an additional advantage — it can be welded so as to exclude the atmosphere during heating, or it can be provided with an evacuation tube (Fig. 6) which is used to remove all air from the billet and then sealed off before extrusion. This technique, with a conventional metal as a "lubricant" has solved the two major problems of reactor materials extrusion.

A number of mechanical and metallurgical considerations determine the type of canning material used. For uranium in the alpha phase (below 1250°F) and thorium at temperatures up to 1600°F, cans are made of copper. Some uranium alloys are considerably harder than pure uranium and steel cans are used. Zirconium and zirconium alloys, at temperatures up to 1400°F, are extruded in copper or brass cans, but above this temperature an alloy of copper and zirconium forms and iron cans are used up to 1600°F. Beryllium is always canned in iron. The upper temperature limit given by the formation of beryllium-iron alloys is 2000°F.

After extrusion, the canning materials are removed by chemical etching in nitric acid, which does not attack zirconium and beryllium and attacks uranium and thorium only very shortly.

Some aluminum-uranium alloys which are normally difficult to extrude have been canned successfully in magnesium.

The canning technique has been applied successfully to simple shapes such as rods and rectangles, but for more complicated shapes the die's conical approach is rather difficult to obtain and dies become very expensive. Tubes are easily extruded with cladding on the outside and inside diameter of the extrusion billet (Fig. 7).

The high cost of metal canning is almost always justified by the relatively excessive cost of the materials to be extruded; a saving of even a very small fraction of these metals justifies a fairly expensive can.

One additional advantage of canning should be noted. Uranium and thorium are radioactive and toxic, and beryllium is exceedingly toxic. With metal cans properly applied, these hazards are eliminated and the metals can be extruded with few precautions in plants without special ventilation facilities.

There are certain applications in which it was found necessary to use uranium in the extruded condition, without further cold work. With fairly heavy copper cans the surface of the uranium after extrusion is rather coarse, necessitating its machining before reactor use. It was found that good surfaces resulted when the copper can was replaced by a 10 mil thick copper plating on the uranium billet. It is doubtful that this technique can be applied to metals which must be extruded at higher temperatures.

Several other methods of extrusion recently have been applied to the extrusion of zirconium and uranium; in all of these, the flow of metal is streamlined.

The Ugine-Sejournet process, in which molten glass is used as a lubricant, is commonly used for the extrusion of steel and high strength alloys, but has been applied with some success to zirconium and to some very hard uranium alloys. In this process the billets

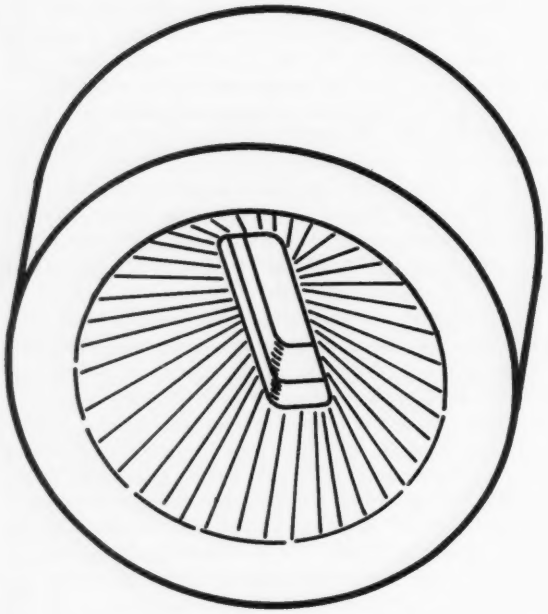


Figure 5. Die used for the extrusion of a rectangular section.

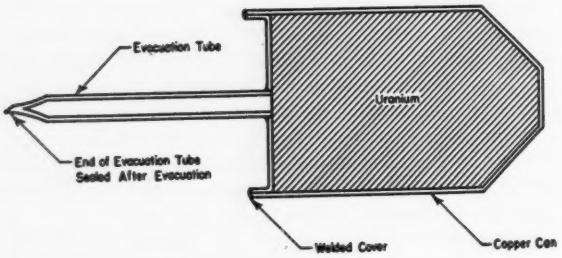
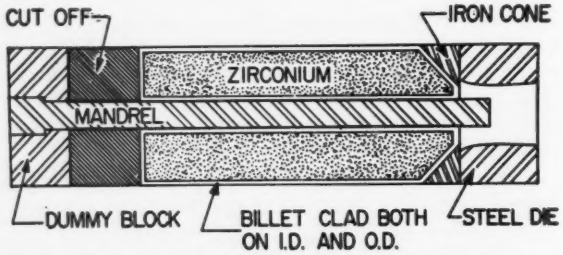


Figure 6. Typical billet with an extrusion can and evacuation tube.



Tooling for tube extrustion with "French" floating mandrel inside hollow billet.

Figure 7. Tube extrusion billet showing O.D. and I.D. cladding.

are heated in a salt bath to prevent excessive contamination and are then rolled on a table covered with glass powder or a glass mat which sticks to the billet and melts. A glass pad is introduced at the die approach in order to provide additional glass lubricant and to form the necessary conical die entrance. The glass chosen must have low viscosity at the temperature of the extruded billet but must form a thin solid layer in contact with the relatively cool tools. The ease with which this viscous layer can absorb most of the shear strain occurring in extrusion is shown schematically in Fig. 8.

Some extruders have found that the salt clinging to the billet after heating is an effective lubricant for uranium. The difficulty with salt is that it possesses a distinct melting point and, not as in glass, a gradual change in viscosity. This means that all conditions have to be controlled most carefully to avoid galling. A conical approach die is always used in conjunction with this technique.

A few final words on the extrusion process should include mention of a further development in the metal-lubricant technique which is of great importance in power reactor fuel element fabrication.

The fuel in nuclear reactors (U, Th or Pu) is never exposed directly to the coolant (a gas, water, or a liquid metal) because of the fuel's poor corrosion resistance and because of the need to contain fission products. All fuels are always clad on all sides by other metals, such as zirconium or aluminum.

The metal lubrication technique already described is particularly suited to the extrusion of clad fuel elements. In this process, called coextrusion, the galling and welding properties of the materials are used to bond them to each other and to the fuel while the metallic can prevents welding to the tools. Fig. 9 shows a billet assembly for the extrusion of a zirconium clad uranium fuel element. The uranium is placed within a zirconium sleeve and a zirconium end plug is provided at each end. The entire assembly is then placed inside a copper can which is evacuated before extrusion. This technique has been considerably refined and is now one of the two most common methods of making clad metallic fuel elements.

OTHER HOT WORKING OPERATIONS:

In other hot working operations, such as rolling and forging, the lubrication problems for reactive metals are the same as those for other metals. The problems are connected mainly with preventing contamination of the metal by the atmosphere or with preventing contamination of the atmosphere by toxic materials. Normally, salt bath heating is used and, in the rolling of uranium, salt is sprinkled on the rolled section to maintain a continuous film. Beryllium and highly enriched uranium in the isotope U-235 are frequently forged and rolled in steel and copper cans respectively. A method called picture-frame rolling, similar to coextrusion, has been developed for the rolling process; the metal to be rolled is placed within a flat can of another metal, usually iron or copper. Fig. 10 shows a typical picture-frame assembly.

COLD WORKING

Drawing of tubing is a severe test of the effectiveness of a lubricant, particularly when tubing is of a reactive metal and plug drawing techniques — in which the tube travels through a die and the plug is stationary — are used.

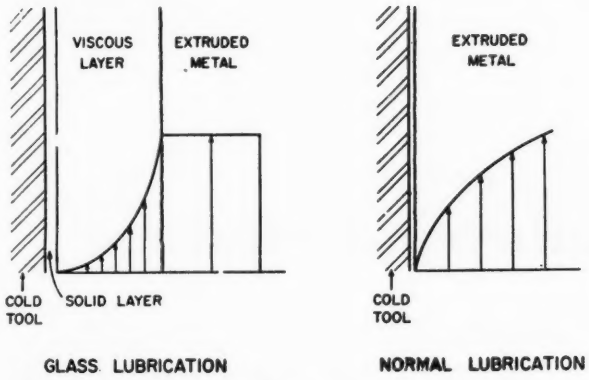
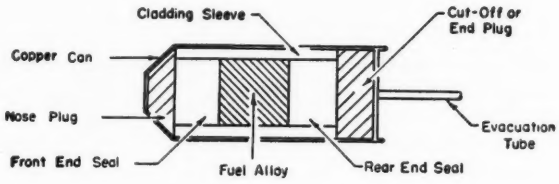


Figure 8. Glass lubrication vs. normal lubrication schematic representation.



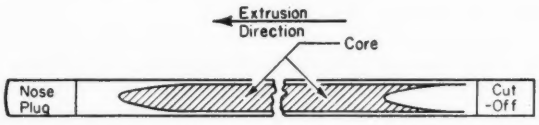


Figure 9. Zirconium clad uranium fuel element.

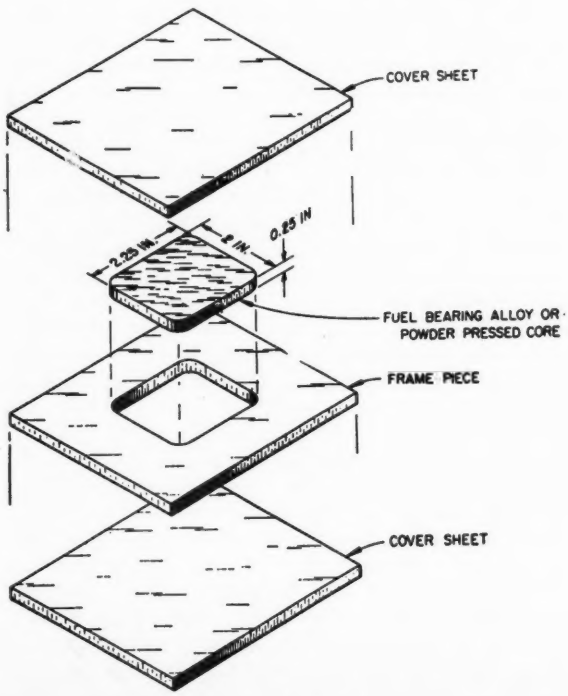


Figure 10. Picture frame technique.

The economic production of zirconium tubing is an important factor in the cost of nuclear power and has become a prime factor in the recent development of uranium oxide as a fuel. Almost always the oxide has to be enclosed in zirconium tubing.

In drawing zirconium tubing, again, almost all conventional lubricants were tried and are still being tried with little success. The first success was accomplished when the copper sheath from canned extrusion was allowed to remain on the zirconium tube; the tubing then drew easily with normal copper drawing lubricants.

This method, however, has two limitations: first, the copper has to be removed before annealing because it would diffuse into the zirconium and make it unsuitable for reactor use; second, the surface of the zirconium under the copper is fairly rough and is not improved greatly by drawing.

In the fabrication of Zr wire, copper has been plated on Zr, to serve as a lubricant, and silver plating is used successfully to produce small uranium wire. Such techniques are nevertheless difficult and expensive to apply to the inside of small diameter tubing.

The next development was the use of solid fiber lubricant. There are a large number of these on the market and others have been compounded in the laboratory. They usually consist of solids such as molybdenum disulfide, copper, copper oxide, zinc, lead, and graphite, dispersed in a number of liquid fast-drying carriers such as lacquer, varnishes, and plastics. These lubricants have been used with some success when the rod drawing technique is used, that is, when a rod is drawn through the die along with the tube, but they are usually not effective in plug drawing.

Another lubricant which showed some promise was a type of water soluble paint. One difficulty with this paint as a lubricant was the near impossibility of its removal from tubes.

Recently this writer, in conjunction with a paint company, has developed a displacement type of coating (ACP-LFN-860) which shows great promise. Other companies have produced phosphate coatings for the same purpose and for use in conjunction with drawing soaps. It has been my experience that thorough drying of this soap is of major importance and a major problem for small tubing. In general these types of coatings have allowed the production of high quality zirconium tubing of all sizes by plug drawing. However, they are far from economical, the drawing speed is limited to very low values (about 12-20 feet/minute), and the bath producing the coating is rather difficult to control.

Another apparently successful and more economical lubricant, commercially available but still in the laboratory development stage, is steel skin #120-G5. This is a mixture of stearates and molybdenum disulfate; it appears to be completely ineffective when used on a bright etched zirconium surface, but prevents galling when the surface is slightly oxidized. Even with this lubricant, drawing speed is limited to about 12 to 20 feet per minute.

At the present time the drawing cost of zirconium tubing is five to 10 times higher than similar costs for conventional metals. This could be greatly reduced by the use of a lubricant which would allow higher drawing speeds and reductions and yet would be easy to apply and remove. *(Cont. on p 273)*

High Temperature Lubricant Studies

*E. E. Klaus and M. R. Fenske**

Basic information on the behavior of hydraulic fluids and lubricants is needed at temperatures above 400°F if successful operation of engines and hydraulic systems is to be achieved at high temperatures. It is necessary first to develop reliable test procedures and techniques covering the measurement of viscosity, lubricity, corrosion, and oxidation and thermal stability at temperatures of 500° to 700°F. Several fluids were evaluated in this manner. These fluids are representative of the different chemical classes, such as silicones, silicates, hydrocarbons and mineral oils, diesters, and halogenated aromatic hydrocarbons.

It was found that the property differences between the various types of fluids at 500° to 700°F were much narrower than exist in the 200° to 350°F range. Data are presented showing the inadequacy of extrapolating 200° to 350°F data as a means of predicting performance at 500°F to 700°F. The behavior of fluids and lubricants in the 200° to 350°F range has been quite well defined in recent years for the materials used in this study. However, there is a paucity of information at 500° to 700°F. This paper attempts to remedy this situation somewhat.

The behavior of hydraulic fluids and engine lubricants in the moderately high temperature range of 200° to 400°F has been investigated extensively in recent years. Much of this work has been done in an attempt to satisfy the increasing demands placed upon these materials by high speed aircraft. With further increases in aircraft speed and power, still higher fluid and lubricant temperatures are predicted.

This paper presents data obtained as part of the high temperature properties of substances showing promise as hydraulic fluids and lubricants.

One object of the paper is to describe some of the tests used and general trends noted in this study. Two other objectives are (a) defining the limitations of organic liquids in the range of 500° to 700°F and (b) developing sound tests to demonstrate these high temperature properties in a reproducible and reliable manner.

At the outset it was found that there were essentially no established test procedures for these temperatures. As a result the development of high temperature procedures and techniques and the evaluation of various fluids proceeded concurrently.

Following are some of the chemical classes that were evaluated: mineral oils, specific hydrocarbons, fluorocarbons, chlorocarbons, mixed halocarbons, polyglycol ethers, phosphate esters, silicate esters, dibasic acid esters, pentaerythritol esters, complex esters, and silicones. Emphasis has been placed on the properties of volatility, viscosity, lubricity, thermal stability, oxidative stability and corrosiveness toward metals.

VISCOSITY PROPERTIES

Viscosities in the range of 500° to 700°F have been determined in modified Ostwald-type capillary viscometers (1). A constant temperature vapor bath, shown in Figure 1, has been used. Thermally stable hydrocarbons are used to obtain the constant vapor temperature that surrounds the viscometer. Biphenyl gives a constant vapor temperature of 490°F at 740 mm Hg pressure, and *meta* terephenyl gives a constant temperature of 707°F at 740 mm Hg pressure. These two hydrocarbons have been used successfully for extended periods in the vapor bath without a measurable change in vapor temperature.

Measured viscosities of various materials at 490° and 707°F are shown in Table 1. Their low-temperature viscosities and viscosity-temperature characteristics are also given for comparison. Persistent problems have been encountered in high-temperature viscosity measurements due to thermal decomposition or high vapor pressure of the test fluids. Evidence of this is shown in Table 1 for essentially all of the fluids at 707°F and about one third of the fluids evaluated at 490°F. A comparison of the measured viscosities and the viscosities extrapolated on the ASTM viscosity-temperature chart (2) from measured values at 210° and 100°F indicates that extrapolation is not adequate for predicting high-temperature viscosities. At 490° and 707°F most of the measured viscosities fall substantially below the values predicted from the ASTM viscosity-temperature chart.

All of the measured viscosities at 707°F are low. These low viscosity levels will impose some practical problems on systems designed for high temperatures. The lack of viscosity will reduce markedly the hydrodynamic

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Pennsylvania State University, Petroleum Refining Laboratory, University Park, Pennsylvania.

Test technique and procedure, except for test temperatures, are in accordance with Spec. MIL-L-7808.

Oxygen adsorption is determined by analysis of the exhaust gases form a Spec. MIL-L-7808 oxidation and corrosion test at the indicated temperature. These data are given for the portion of the oxidation test following the induction period. Test Conditions: Air Rate = 5 ± 0.5 L./hr. at Atmosphere Pressure Test Fluid charged = 100 ml.

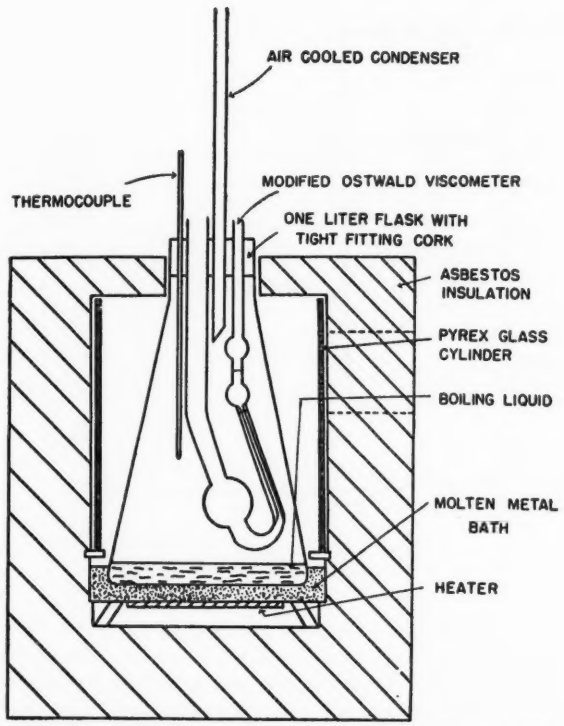

Figure 1. Apparatus used in the determination of high temperature viscosities.

component of lubrication and place more emphasis on boundary lubrication. Closer tolerance seals and port clearances in slide valves, pump, etc., will be required to control both external and internal leakage.

In many of the current hydraulic fluids and lubricants, viscosity levels have been raised and viscosity-temperature properties improved by the use of polymeric thickeners or viscosity index (VI) improvers. Some of the polymeric materials in use show fair thermal stability at 500°F, but none of the materials investigated show suitable thermal stability at 600° and 700°F. Accordingly, if increased viscosity at 600° and 700°F and higher viscosity indices are to be achieved via polymers, new types of thermally stable polymers will have to be developed.

LUBRICITY

The low viscosities at high temperatures will place increased emphasis on boundary lubrication (the chemical component of lubricity). Lubricity testing at 500° to 700°F is hampered to some extent by the lack of information on suitable bearing metals for use in this temperature range. The use of low-temperature devices, such as hydraulic pumps, for high-temperature lubricity testing is usually further complicated by metal expansion problems and changes in the physical or chemical properties of the bearing surfaces. This laboratory has used a Vickers vane pump and Shell four-ball wear machine for high-temperature lubricity studies.

The Vickers vane pump has been used to evaluate lubricity for temperatures up to 500° and 600°F. This pump is shown in Figure 2 and the entire high-temperature pump test stand in Figure 3. This vane pump is self-compensating for expansion and wear. That is, the vanes are forced out against the cam ring by centrifugal force and the valve plate is forced against the sides of the vanes by hydraulic pressure. These wearing parts are all fabricated from steel. Thus, high temperature differential metal expansion problems are not encountered with this pump.

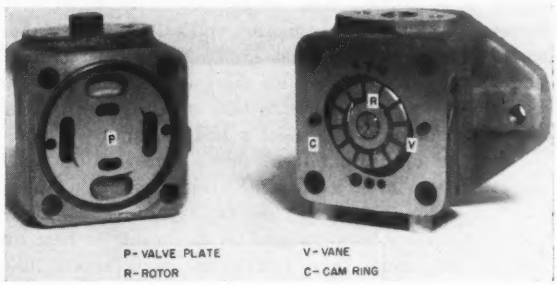

Figure 2. Vickers model VT4-100-40-75-10 vane pump.

TABLE 1. HIGH TEMPERATURE VISCOSITIES

Where only a single value is given, the deviation or change in viscosity is less than one percent for a period of 30 minutes. Where two values are shown, change in viscosity is over a period of 30 minutes.

Test Fluid	Centistoke (cs) Viscosity			ASTM Slope (210° to 100°F)	cs Visc. at 490°F			cs Visc. at 707°F		
	0°F	100°F	210°F		Exper.	Extr.[3]	% Dev.[4]	Exper.	Ext.[3]	% Dev.[4]
Di-2-Ethylhexyl Sebacate	193	12.7	3.34	0.702	0.77-0.76	0.84	−8	—[1]	0.52	—
Pentaerythritol Ester	615	22.4	4.54	0.717	0.84-0.82	0.96	−15	0.42-0.59	0.56	−27
Naphthenic Mineral Oil	156,000	201	12.0	0.815	1.16	1.21	−4	0.57-0.66	0.62	−8
Napththenic Mineral Oil	3,900	44.6	5.74	0.779	0.86	0.98	−11	0.45	0.55	−18
Polyamyl Naphthalenes	160,000[2]	133	8.16	0.897	0.80	0.93	−14	—[1]	0.49	—
Polyolefin Hydrocarbons	14,400	111	12.5	0.667	1.60	1.61	−1	—[1]	0.85	—
Polyolefin Hydrocarbons	804	15.4	3.10	0.829	0.62	0.69	−10	—[1]	0.42	—
Polyglycol Ether	2,000	40.5	7.37	0.642	1.39-1.38	1.34	+4	—[1]	0.76	—
Chlorinated Aromatic Hydrocarbon	SOLID	42.5	3.17	1.15	0.55	0.48	+15	—[1]	—	—
Tricresyl Phosphate	26,700	38.3	4.48	0.895	0.76	0.74	+3	—[1]	0.43	—
Silicate Ester Fluid A	196	32.6	11.5	0.377	2.63-2.59	2.99	−12	—[1]	1.84	—
Methyl Phenyl Silicone	234	44.4	15.5	0.346	3.25	3.42	−5	1.46-1.37	2.30	−35
Chlorine—Containing Silicone	287	59.9	21.2	0.315	4.52	5.27	−14	2.2-2.0	3.02	−25

(1) A reliable value could not be determined because of decomposition or boiling.
(2) Extrapolated value.
(3) Determined from "Tables for determination of ASTM slope and prediction of viscosities."
(4) Percent deviation from extrapolated value.

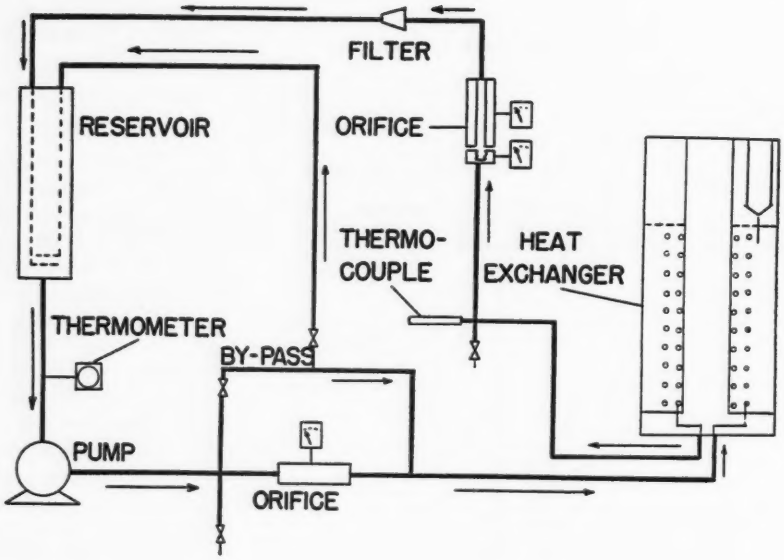

Figure 3. Flow diagram of high-temperature pump test unit.

Previous low-temperature wear studies with Vickers vane pumps (3) indicate that combined hydrodynamic and boundary lubricity effects are present. Hydrodynamic lubrication is predominant at viscosity levels of greater than 25 centistokes, and boundary lubrication predominates at viscosities below about five centistokes.

The high temperature pump test stand shown in Figure 3 is simple. The entire unit is mounted in a transite box to provide insulation and safety. The orifice between the pump and heat exchanger is used to load the pump. The second orifice downstream from the heat exchanger is used to measure flow rate. The high-temperature heat exchanger uses a bed of fluidized solids. The method of heating the fluid is quite critical since many of these high temperature tests are made at the point of incipient thermal decomposition of the fluid. Excessive surface temperatures on the heater or heat exchanger can, under these conditions, cause severe fluid decomposition which is not typical of operation at the indicated bulk fluid temperature. The fluid reservoir is vented to the atmosphere through a 0.5-inch diameter tube.

The results of standard four-hour tests at 500°F in this pump unit are shown in Table 2. In all cases where colloidal metal has been observed in the reservoir, excessive wear on the valve plate has been noted. The valve plate is relatively soft steel compared with the vanes, rotor, and cam ring. Significant differences are noted in wear and flow rate among the various fluids evaluated. There appears to be no obvious correlation of delivery rate and wear with viscosity of the test fluid. Wear and particularly delivery rate are believed to be dependent on boundary lubricity properties of the fluids.

The effect of lubricity additives on mineral oils and esters is illustrated in Table 3. Increasing the viscosity of a naphthenic mineral oil with polybutene gives some increase in volumetric efficiency. The use of tricresyl phosphate in di-2-ethylhexyl sebacate shows an improvement in vane wear. The use of a dialkyl acid phosphite in mineral oils or esters produces a marked reduction in vane wear and an increase in volumetric efficiency. Examination of the worn parts indicates that good mating of the parts from a chemical polishing action is the probable mechanism causing these improvements. These data

TABLE 2. VICKERS VANE PUMP TESTS AT 500°F WITH VARIOUS FLUID TYPES

Tests Conducted in the PRL High Temperature Pump Test Unit

Test Fluid	Test Time at 500°F, Hours	Flow Rate, gpm at 500°F and Indicated System Pressure psi		Fluid Viscosity at Test Temp., cs	Avg. wt. Loss per Vane, mg	Appearance of Colloidal Metal in Fluid
		Initial	Final			
Di-2-Ethylhexyl Sebacate[1]	4	2.8 (700)	2.4 (700)	0.8	0.2	No
Pentaerythritol Ester[1]	4	2.8 (700)	2.4 (700)	0.8	2.3	No
Naphthenic Mineral Oil (Neutral)	4	1.8 (750)	1.8 (750)	0.9	0.0	No
Polyolefin Hydrocarbons[1]	4	3.6 (700)	2.9 (700)	1.6	0.4	No
Polyglycol Ether	4	3.5 (700)	3.3 (700)	1.4	0.1	No
Chlorinated Aromatic Hydrocarbon	2.3	4.4 (700)	<1.0 (700)	0.6	0.7	No[2]
Silicate Ester Fluid A	0	1.6 (700)	1.0 (600)	2.6	4.0	Yes[3]
Silicate Ester Fluid B	0.5	1.8 (700)	1.2 (600)	0.9	1.3	Yes[3]
Chlorine-Containing Silicone	0	<1.0 (400)	—	4.5	1.3	Yes[3]

(1) These fluids contain 1.0 weight percent tricresyl phosphate.
(2) Some valve plate wear was noted in this test.
(3) Excessive valve plate wear was noted in these tests.

TABLE 3. EFFECT OF LUBRICITY ADDITIVES ON TESTS AT 500°F WITH A VICKERS VANE PUMP

Tests conducted in PRL high temperature pump test unit. Test temperature = 500°F. (Pump inlet temperature); Maximum fluid temperature = 525°F; Test time = 4 hours at 500°F.

Test Fluid[1] (additive conc. expressed as wt. %)	Flow Rate at Test Temp., gpm		Fluid Visc. at Test Temp., cs	Avg. Wt. Loss Per Vane, mg
	Initial	Final		
Naphthenic Mineral Oil.....	1.8	1.6	0.9	0.0
Naphthenic Mineral Oil + 5.0 Polybutene Thickener.....	3.2	3.0	2.2	1.2
Naphthenic Mineral Oil + 0.5 Dialkyl Hydrogen Phosphite.....	4.3	4.0	0.9	+1.3[2]
Di-2-Ethylhexyl Sebacate.....	3.4	2.7	0.8	2.3
Di-2-Ethylhexyl Sebacate + 1.0 Tricresyl Phosphate.....	2.8	2.4	0.8	0.2
Di-2-Ethylhexyl Sebacate + 0.2 Dialkyl Hydrogen Phosphite....	3.9	3.6	0.8	0.2
Pentaerythritol Ester + 1.0 Tricresyl Phosphate.....	2.8	2.4	0.8	2.3
Pentaerythritol Ester + 0.5 Dialkyl Hydrogen Phosphite....	4.2	3.6	0.8	0.9

(1) All fluids contain an oxidation inhibitor.

(2) A white solid was deposited on the vanes during the test. This coating predominated on the part of the vane where no metal-to-metal contact occurred.

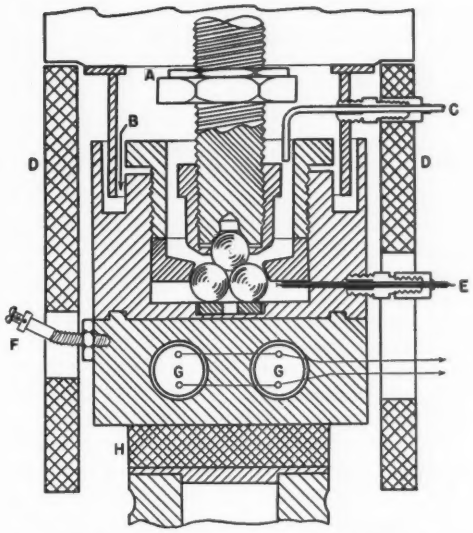

Figure 4. Shell four-ball machine modified for high-temperature studies.

indicate that at least some lubricity additives are effective in this high temperature range.

A series of tests covering the temperature range of 100° to 500°F have been made with di-2-ethylhexyl sebacate and silicate ester fluid B. These data are in Table 4. They indicate no sharp break in lubricity for the diester over this temperature range. The silicate fluid shows adequate lubricity at 100° and 300°F. Distinct lubricity difficulties are noted at 400° and 500°F with this fluid.

In almost all cases of poor lubricity at 500°F, colloidal metal in the test fluid and excessive valve-plate wear have been noted. As indicated previously, the valve plate is a soft steel. A hardened valve plate has been used in a revaluation of the fluids producing high wear and colloidal metal. In all cases, improved operating characteristics were obtained with the hardened valve plate. In no case was appreciable valve-plate wear noted. Operational behavior of the silicates, silicone, and chlorinated hydrocarbon with the hardened valve plate were still inferior to those of the mineral oils and esters with standard parts.

As an additional lubricity tester at high temperatures, the Shell four-ball wear machine was used. This unit, modified for high temperature use, is shown in Figure 4. These modifications include (1) more heater capacity, (2) more fluid capacity in the ball pot (30 ml), (3) an enclosed atmosphere over the ball pot, and (4) insulation around the ball pot. The enclosed atmosphere over the ball pot permits the use of inert atmospheres as well as controlled air contact and a reduction in volatilization losses.

Standard one hour lubricity tests in the Shell four-ball wear machine are shown in Table 5 for various fluid types at 167°, 500°, and 600°F. This test range is covered using 52-100 bearing-steel balls. These balls are designed primarily for use at temperatures below 350°F and

TABLE 4. THE EFFECT OF TEMPERATURE ON LUBRICITY FOR TWO FLUIDS IN A VICKERS VANE PUMP

Test pressure = 700 psi

Test Fluid	Test Temp. °F (Pump Inlet Temp.)	Test Time at Test Temp., Hrs	Flow Rate at Test Temp., gpm	Fluid Visc. at Test Temp., cs	Avg. Wt. Loss Per Vane, mg	Appearance of Colloidal Metal in Fluid
Silicate Ester Fluid B.....	100 ± 10	4	5.8	12.0	0.2	No
	300 ± 20	4	4.9	1.9	0.7	No
	400 ± 10[1]	4[1]	4.3-2.8[1]	1.2[1]	1.5[1]	Yes
	500 ± 10[2]	0.5[2]	1.8-1.2[2]	0.9[2]	1.3[2]	Yes
Di-2-Ethylexyl Sebacate + 0.5 wt % Phenothiazine.....	100 ± 10	4	5.8	12.7	0.4	No
	300 ± 20	4	5.4	1.8	0.4	No
	400 ± 10	4	4.9-4.6	1.0	+0.3	No
	500 ± 10	4	3.4-2.7	0.8	2.3	No

(1) Excessive valve plate wear noted after completion of test. A small amount of colloidal metal was observed in reservoir during operation.

(2) Operation at 500°F and 700 psi was terminated after 0.5 hrs. because stead operation could not be maintained. Colloidal metal appeared in reservoir during test. Excessive valve plate wear was noted after completion of test.

TABLE 5. HIGH TEMPERATURE LUBRICITY STUDIES IN THE SHELL FOUR-BALL WEAR MACHINE

Test conditions include: Test time = 1 hour; test speed = 850 rpm; test temperature as indicated; test bearings are grade 1 quality of the indicated steel. Tests at 500° and 600°F have been accomplished by introducing air at a rate of 0.7 liters per hour into the controlled atmosphere over the ball pot.

Test Fluid	Average Wear Scar Diameter In mm.											
	At 167°F With 52-100 Steel			At 500°F With 52-100 Steel			At 600°F With 52-100 Steel			At 600°F With M-10 Tool Steel		
	1 kg	10 kg	40 kg	1 kg	10 kg	40 kg	1 kg	10 kg	40 kg	1 kg	10 kg	40 kg
Di-2-Ethylhexyl Sebacate	0.26	0.55	0.78	0.24	0.68	1.38	0.29	0.97	1.12	0.29	0.47	0.93
Pentaerythritol Ester	0.20	0.58	0.86	0.25	0.58	1.15	0.45	0.52	0.91	—	—	—
Naphthenic Mineral Oil	0.23	0.58	0.60	0.31	0.47	1.38	0.20	0.57	1.71	0.23	0.51	1.04
Polyolefin Hydrocarbons	—	—	—	0.21	0.32	1.08	0.29	0.86	1.69	0.27	0.78	1.10
Chlorinated Aromatic Hydrocarbon	0.22	0.30	0.58	0.61	0.97	1.19	0.88	0.87	1.17	0.55	0.83	1.20
Silicate Ester Fluid A	0.35	0.64	0.89	0.28	0.81	1.62	0.29	1.38	1.30	0.42	0.58	1.71
Silicate Ester Fluid B	0.21	0.44	0.63	0.35	0.72	1.43	0.78	1.17	1.19	0.98	1.17	1.43
Chlorine—Containing Silicone	0.18	0.31	0.67	0.39	0.77	1.56	0.34	0.63	1.90	0.44	0.93	1.56

show considerable property deterioration at 500° and 600°F. Tests at 600°F with M-10 tool-steel balls are also shown. M-10 tool steel maintains good property stability at 600°F.

There is a general increase in wear values with temperature for the 52-100 steel balls for all of the fluid types shown. Comparing the results of 52-100 steel at 167°F with M-10 tool steel at 600°F, the increase in wear values is more marked at the high temperature for the silicates, silicone, and chlorinated-aromatic hydrocarbon than for the mineral oils and esters.

The effect of lubricity additives in di-2-ethylhexyl sebacate and a mineral oil is illustrated for the temperature range of 167° to 600°F in Table 6. The 167°F data are for 52-100 steel balls while the 600°F data are for M-10 tool-steel balls. These show that the effect of certain lubricity additives persists at 600°F.

In general, the lubricity data obtained thus far show some agreement between the Vickers vane pump and the Shell four-ball wear machine at elevated temperatures. These data point up the need for using realistic bearing metals in high-temperature lubricity studies. The effectiveness of lubricity additives at 500° and 600°F can be shown. Differences in the temperature coefficient of lubricity are indicated for different chemical compositions. Frequently the compositions which exhibit the best oxidation and corrosion stability at elevated temperatures have poor lubricity properties.

TABLE 6. EFFECT OF LUBRICITY ADDITIVES AT HIGH TEMPERATURES AS MEASURED BY THE SHELL FOUR-BALL WEAR MACHINE

Test conditions include: Test time = 1 hour; test speed = 850 rpm; test temperature as indicated; test bearings are grade 1 quality of the indicated steel. Tests at 600°F have been accomplished by introducing air at a rate of 0.7 liters per hour into the controlled atmosphere over the ball pot.

Test Fluid	Average Wear Scar Diameter in mm.					
	At 167°F With 52-100 Steel			At 600°F With M-10 Tool Steel		
	1 kg	10 kg	40 kg	1 kg	10 kg	40 kg
Di-2-Ethylhexyl Sebacate (PRL 3509)	0.26	0.55	0.78	0.29	0.47	0.93
PRL 3509 + 5.0 wt. % Tricresyl Phosphate	0.17	0.23	0.35	0.33	0.43	0.84
PRL 3509 + 5.0 wt. % Dialkyl Hydrogen Phosphite	0.15	0.24	0.40	0.36	0.51	0.54
Naphthenic Mineral Oil (PRL 3457)	0.23	0.58	0.60	0.23	0.51	1.04
PRL 3457 + 0.5 wt. % Dialkyl Hydrogen Phosphite	0.15	0.31	0.48	0.29	0.39	0.42

THERMAL STABILITY

The term *thermal stability* as used here refers to the fluid's stability at a given temperature under an inert nitrogen atmosphere. Two types of thermal-stability tests have been used. In one type the test fluid, under an atmosphere of nitrogen, is confined only by a liquid seal in a glass apparatus. This apparatus is shown in Figure 5. Volatile decomposition products can escape from this test system under a positive pressure of approximately four inches of test fluid. The second test is conducted under a nitrogen blanket in a stainless steel pressure cylinder as shown in Figure 6. In this test the volatile decomposition products are confined in intimate contact with the fluid for the test duration.

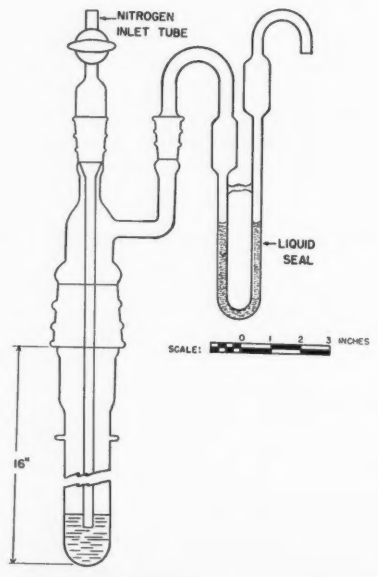

Figure 5. Apparatus for high-temperature thermal stability studies.

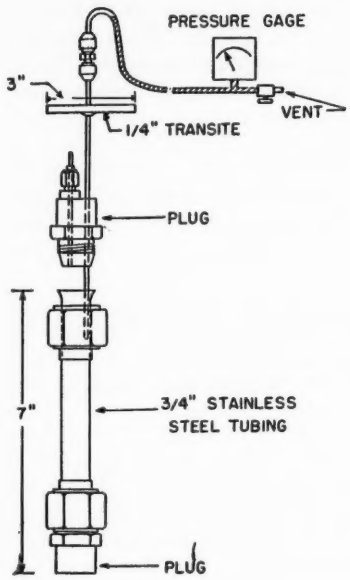

Figure 6. Construction details of pressure cylinder for high-temperature thermal-stability studies.

Results of six-hour thermal stability tests at 600° and 700°F for various chemical classes are shown in Table 7. Both test techniques described above have been used in this evaluation. The test temperature chosen for each fluid (if under 700°F) is the highest test temperature at which the fluid exhibits sufficient thermal stability to persist for the test time as a homogenous liquid product. It can be seen that, with the exception of the chlorinated-aromatic hydrocarbon, all of the fluids show substantial property changes under both types of thermal stability tests at temperatures of 700°F or below. In general, the chlorinated-aromatic hydrocarbon, mineral oil, and silicone are among the more thermally stable of the materials tested. Data from the pressure cylinder indicate that in all cases pressure is generated by volatile materials formed during the course of the thermal-stability test. In most cases the decomposition products are of sufficient volatility to exert a pressure on the gage after cooling to room temperature. These volatile materials are in most cases inflammable. In high-temperature hydraulic and lubricant systems it may be necessary to cope with volatile inflammable components which are quite different from the initial inflammability of the fluid. Of the fluids tested, only the chlorinated-aromatic hydrocarbon is essentially fireproof.

In the study of thermal stability it has been found that the best thermal stability value is obtained with pure compounds in all glass equipment. In many cases thermal stability is adversely affected by the presence of metals or additives.

OXIDATION AND CORROSION

Oxidation and corrosion behavior are the most critical properties of a high-temperature lubricant used in an open lubricant system. Oxidation effects are less critical in hydraulic systems where the entire unit can be sealed and even pressurized with an inert gas.

The discussion of high-temperature oxidation and corrosion properties requires the introduction of a new concept. At temperatures of 350°F or below, the stable life, or induction period, of a lubricant is normally used to describe oxidation and corrosion behavior. This stable life, or induction period, is the length of time at a given temperature during which little or no oxygen is assimilated by the fluid and only minor property changes are encountered even though ample oxygen is available. The stable life, or induction period, decreases logarithmically with increasing temperature. A typical plot of induction period versus temperature is shown in Figure 7 for a well-inhibited dibasic acid ester. It can be seen from this plot that at 500°F and above there is essentially no induction period left.

At temperatures of 500°F and above, new criteria for oxidation stability must be used. Two properties of the fluid are considered pertinent in this type of oxidation and corrosion behavior. The first is oxidation rate and the second is oxygen tolerance. This is the amount of oxygen that can be assimilated for a specified property change and amount of metal corrosion.

A study of variables affecting the rate of oxidation of mineral oils and dibasic acid esters at 500°F has been made. It has been found that inhibitors will reduce the

TABLE 7. THERMAL STABILITY CHARACTERISTICS OF SEVERAL CLASSES OF HIGH TEMPERATURE FLUIDS

Thermal stability tests in the glass apparatus were conducted for the indicated time at the indicated temperature under a blanket of nitrogen. The unit is sealed with a liquid seal of the test fluid. The seal allows passage of gas out or air in to the system on a pressure differential of about 0.2 psi.
Thermal stability tests in the steel pressure cylinder are conducted at the indicated conditions of time and temperature. Twenty ml of test fluid are sealed in the pressure cylinder under one atmosphere of nitrogen.

	Thermal Stability Test in Glass					Thermal Stability Test in Steel Pressure Cylinder					
								Gage Pressure psi After Test			
Test Fluid	Test Temp., °F	Test Time, hr.	Volatility Loss, wt %	Visc. Change at 100°F. %	Neut. No. Increase (mg KOH/ gm Oil)	Test Temp., °F	Test Time, hr	At Test Temp.	At Room Temp.	Viscosity Change at 100°F, %	Neut. No. Increase (mg KOH/ gm Oil)
Di-2 Ethylhexyl Sebacate	600	6	2	−13	25.2	600	6	72	0	−6	31.4
Pentaerythritol Ester	700	6	16	+23	6.7	650	2.5	270	72	−5	46.9
Naphthenic Mineral Oil	700	6	2	−50	0.0	700	6	158	23	−55	0.1
Polyolefin Hydrocarbons	600	6	4	−12	0.0	600	6	138	0	−63	0.0
Polyglycol Ether	600	6	34	−54	2.4	600	1.5	281	52	−49	0.7
Chlorinated Aromatic Hydrocarbon	700	6	0	+3	0.2	750	6	60	4	+12	0.3
Silicate Ester Fluid A	700	6	8	−41	0.2	700	2.3	279	51	−68	0.1
Silicate Ester Fluid B	600	6	0	−34	2.9	700	0.8	275	25	−42	3.8
Methyl Phenyl Silicone	700	6	4	−34	0.0	700	6	55	0	−28	0.0
Chlorine-Containing Silicone	700	6	2	0	6.4	700	6	106	15	−23	8.4

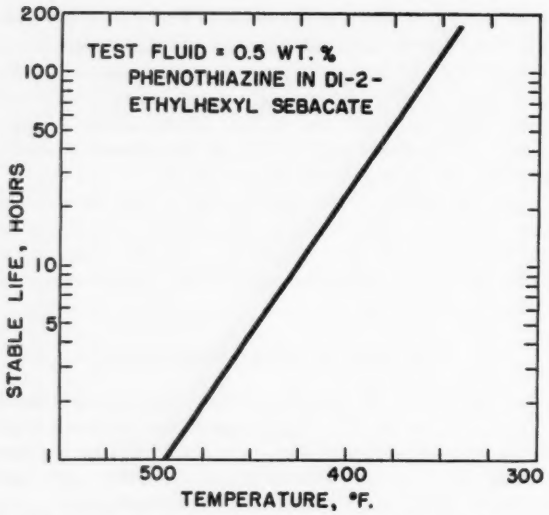

Figure 7. Effect of temperature on oxidation stability.

rate of oxidation for an inital period of oxidation, and that oxidation rate can be increased by increasing the air rate, improving the intimacy of the air-oil contact, lengthening the time of the air-oil contact, or increasing the partial pressure of oxygen. Air rates of 0.6 to 30 liters of air per hour for 100 ml of fluid were used in this study. There is no indication of a limiting rate of oxidation at 500°F.

A comparison of oxidation rate has, therefore, been made using a set of standard, relatively mild test conditions at 500°F. The test conditions and techniques are a modification of the Spec. MIL-L-7808 oxidation and corrosion test (4). The exhaust-gas stream is analyzed periodically for oxygen content to determine the rate of oxidation quantitatively. The effect of temperature on oxidation rate after the induction period is shown for di-2-ethylhexyl sebacate in Figure 8.

A comparison of oxidation rates at 500°F for various fluid types is shown in Table 8. These data also show the oxygen tolerance of these materials. In all cases, except the chlorinated-aromatic hydrocarbon and the methyl phenyl silicone, the oxidations have been carried out to the assimilation of 75 to 90 percent of the oxygen required to produce a solid oxidation product after cooling to room temperature. It can be seen from these data that there are reasonable differences in both oxidation rate and oxygen tolerance as chemical type varies.

Similar oxidation rate and oxygen tolerance data are shown for various fluid types at 700°F in Table 9. The tests at 700°F have been conducted with and without metal catalysts. It is interesting to note that the metal catalysts have no appreciable effect on the rate of oxidation. The presence of metals does have a profound effect on oxygen tolerance in most cases. In both tests at 700°F, the chlorinated-aromatic hydrocarbon shows a very low rate of oxidation and essentially no property changes. The mineral oil at 700°F shows no effect of metals on oxygen tolerance. The mineral oil shows better oxygen tolerance at 700° than at 500°F.

The effect of temperature on oxidation rate and oxygen tolerance is shown for a mineral oil and di-2-ethylhexyl sebacate. The rate of oxidation as a function of temperature for these fluids is plotted in Figure 8. These data indicate a steadily increasing rate of oxidation with increasing temperature over the range of 450° to 700°F.

In general, the mineral oil shows an increasing oxygen tolerance, based on dirtiness, viscosity change, and neutralization number increase, with increasing temperature. Some evidence of this same trend is shown for the di-2-ethylhexyl sebacate over the temperature range of 347° to 500°F. Thermal instability at 600°F and above causes a marked change in the type of products in the oxidation test.

These oxidation and corrosion data show that very few chemical types are resistant to oxidation at 500° to

TABLE 8. OXIDATION AND CORROSION CHARACTERISTICS OF SEVERAL FLUIDS AT 500°F.

Procedures and techniques in accordance with Spec. MIL-L-7808.

Test conditions include: Test temperature = 500 ± 5°F; test time as indicated; air rate = 5 ± 0.5 liters per hour; fluid charged = 100ml; and metal catalysts = one inch squares of copper, steel, and aluminum sheet.

Test Fluid	Di-2-Ethylhexyl Sebacate	Penta-erythritol Ester	Naph-thenic Mineral Oil	Poly-olefin	Poly-glycol Ether	Chlorinated Aromatic Hydro-carbon	Silicate Fluid A	Ester Fluid B	Methyl-phenyl Silicone	Chlorine-Containing Silicone
Test Time, hrs [2]	40	40	30	40	40	120	117	40	124	75
Oxygen Absorbed (Mols/426 gm Fluid) [1]	1.72	1.95	1.06	2.14	2.88	0.30	1.83	1.62	1.40	0.58
Rate of Oxygen Absorption (g/hr)	0.28	0.32	0.23	0.35	0.47	0.02	0.10	0.26	0.07	0.05
Volatility Loss, wt. %	5	15	1	20	33	4	33	45	6	3
Viscosity Increase at 130°F, %	164	4550	352	255	92	12	120	1550	112	15,400
Neut. No. Increase (mg KOH/gm Fluid)	17.0	17.5	3.3	3.8	7.9	0.0	2.3	0.5	0.2	0.9
Fluid Insolubles (Sludge), wt. %	0.9	1.7	1.5	Trace	0.2	Trace	7.9	0.2	None	Trace
Corrosion of Metal Specimens, mg/cm²										
Copper	0.75	0.13	+0.05	0.02	0.15	6.37	0.53	0.05	+0.08	1.35
Steel	0.09	12.05	0.02	0.00	0.67	0.09	+0.02	0.59	+0.02	+0.06
Aluminum	0.00	0.03	+0.01	0.00	0.02	0.02	0.00	0.00	0.01	+0.01

(1) Amount of oxygen consumed determined by frequent sampling of exhaust gases and analysis for oxygen. Mols of oh_2 per 426 gm of oil has been used as a common basis of comparison. The molecular weight of Di-2-Ethylhexyl Sebacate is 426.

(2) The length of the test was chosen to illustrate the longest test time for which moderate property changes were obtained.

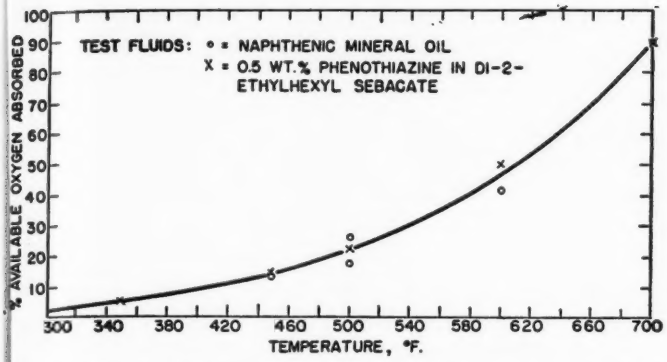

Figure 8. Oxygen assimilated as a function of temperature.

700°F. Those materials which show the best oxidation and corrosion resistance appear to be relatively poor lubricants. The oxidation studies do show that many of the materials evaluated can assimilate reasonably large quantities of oxygen before property changes and metal corrosion become excessive.

The data given here suggest two approaches to high-temperature hydraulic and lubricant system design: (1) a closed system where oxygen can be excluded or markedly limited, and (2) an open system where air cannot be excluded and the lubricant life in contact with the air will be within the oxygen tolerance of the lubricant. In the latter case, a small amount of lubricant would be used at one time and then discarded.

In the region of 700°F, further progress in the stability of lubricants will be limited. The major advance in high-temperature lubricant systems will probably result from a better understanding of fluid behavior at high temperatures and changes in the mechanical design of fluid and lubricant systems to take advantage of whatever thermal stability and good oxygen tolerance is available.

ACKNOWLEDGMENT

This research was supported in part by the United States Air Force under Contract AF33(616)2851 and monitored by the Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

BIBLIOGRAPHY

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(2) American Society for Testing Materials (Committee D-2), ASTM, "Standards of Petroleum Products and Lubricants," 1953.
(3) Klaus, E. E., "Wear and Lubrication Characteristics of Some Mineral Oil and Synthetic Lubricants," Ph.D. Thesis, Pennsylvania State University, 1952.
(4) Military Specification MIL-L-7808, "Lubricating Oil, Gas Turbine, Aircraft," 1952.

Friction of PTFE Dry Bearings

(Cont. from p. 261)

constant for all samples at 1.7:1 on a volume basis. From the plot, it can be seen that increased compressive strength can be achieved by decreasing the amount of PTFE.

Stability to water of resin-bonded compositions was determined by conventional methods. Samples of Compositions 7, 8, 11 and pure PTFE were oven-dried at 185°F until no changes in weight were observed. Measurements of length and weight were taken before and after 48 hours immersion in water at 212°F. Compositions containing an alpha cellulose filler showed the greatest change, whereas those containing wollastonite (calcium silicate) showed very slight change. PTFE was not affected by water in this test. The results are shown in Table 5. Attempts to reduce the hydrophilic character of the alpha cellulose by silicone treatments prior to the mixing of the ingredients did not materially affect the results.

The effect of hot oil was determined on resin-bonded Compositions 9 and 10 and PTFE-bonded Sample B. Disk samples were measured for changes of hardness, thickness and diameter after 240 hours immersion in an SAE 20, non-additive, premium grade crankcase oil which was heated to 250°F. In all cases, the changes in dimensions were less than 1 percent and the hardness change was negligible.

TABLE 5.
EFFECT OF WATER ON RESIN-BONDED MATERIALS

Composition	*Filler*	*Weight Change*	*Length Change*
10	Cellulose, Alpha	5.7%	0.7%
9	Asbestos	2.7	0.4
11	Wollastonite	0.8	0.1
Pure PTFE	None	0.0	0.0

Thermal expansion measurements were made using a concentric quartz tube dilatometer. A linear variable differential transformer was used to sense changes in length. Expansion measurements were obtained from 70° to 350°F. Molded cylindrical samples of resin-bonded compositions showed anisotropic character — the axial change being greater than the radial change. Typical values are those obtained on Composition 7:

Radial change ..... 7.8 x 10^{-6} per °F
Axial change ..... 26.8 x 10^{-6} per °F

We do not have comparative results for PTFE-bonded materials.

Lubrication Problems in Fabrication Of Nuclear Reactor Metals

(Cont. from p. 265)

Problems similar to those of tube drawing exist for deep drawing and other forming operations for the reactive metals. Cold forming operations not involving friction, such as rolling, present no special problems.

CONCLUSION

Two illustrations have been given of lubrication problems in the fabrication of metals for reactor use. As power reactors become more competitive with conventional fossil fuel, increased emphasis will be placed on economy in the fabrication of the required metal parts.

Improvements in lubrication techniques are among the most important factors in effecting significant savings.

REFERENCES

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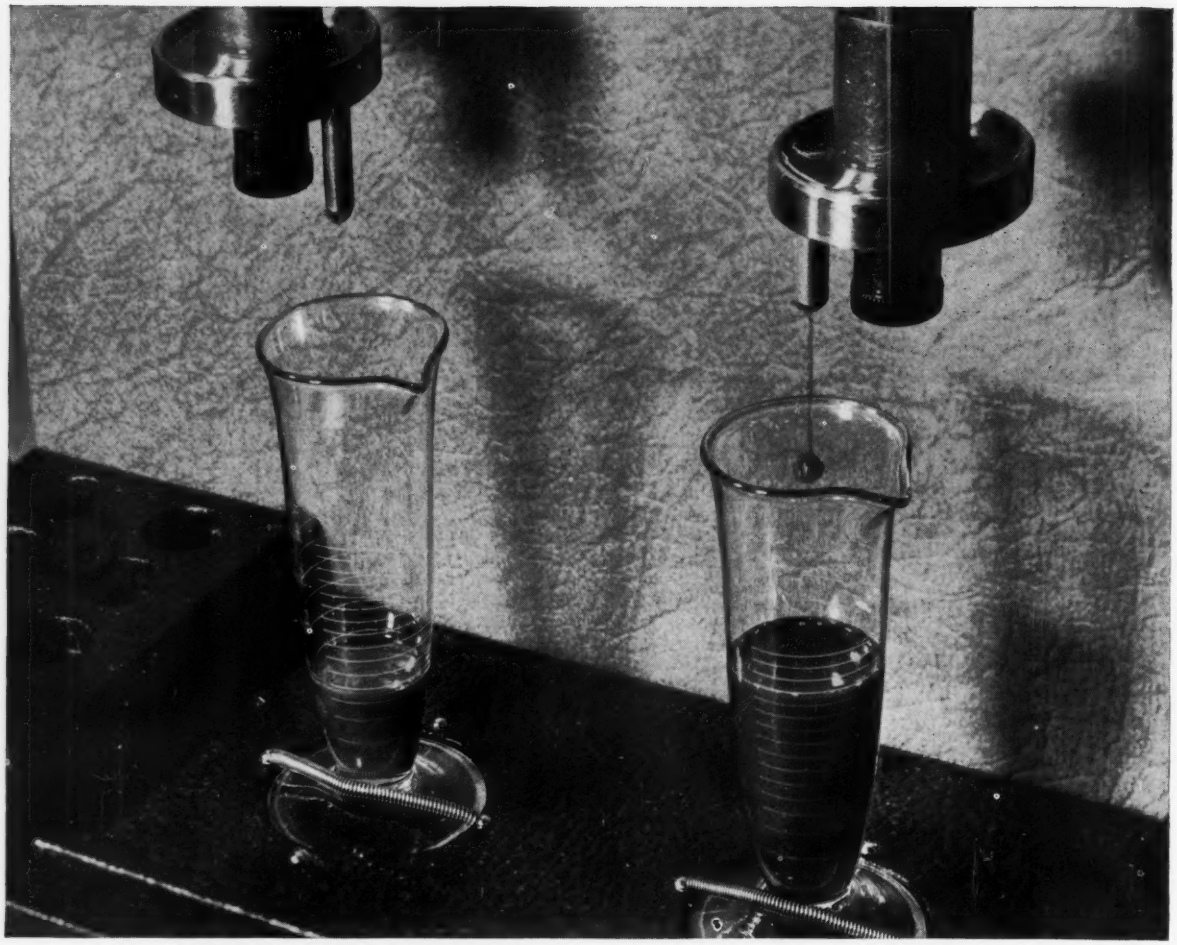
3. P. Loewenstein, "The Extrusion of Uranium," *Nuclear Metallurgy* (vol. IV) IMD Special Report Series No. 4.
4. B. Lustman and F. Kerze, Jr., "The Metallurgy of Zirconium," McGraw-Hill Book Co., Inc., 1955.



The oils collecting in these graduates are being forced, at 100 psi, through two sintered bronze bearings. Although each oil has the same viscosity, the Suntac on the left is leaking *only one quarter as much as* the straight oil on the right.

Desk-top demonstration proves that SUNTAC HYDRAULIC OILS can cut your oil losses . . . up to 75%

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ACHESON

dispersions digest

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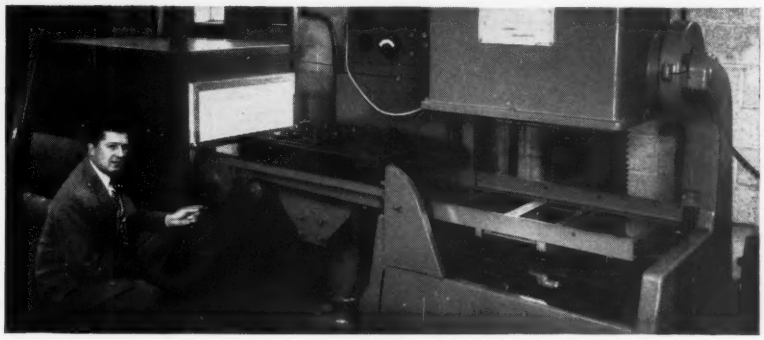
COLLOIDAL GRAPHITE, MOLYBDENUM DISULFIDE, VERMICULITE, AND OTHER SOLIDS

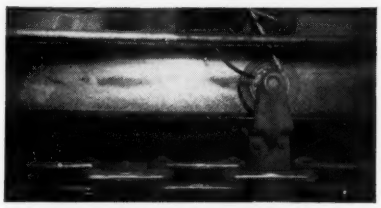
'DAG' DISPERSIONS SHRUG OFF HEAT, KEEP PRODUCTION ROLLING

With temperatures up to 1600° F. and above being generated in various types of industrial ovens, furnaces and kilns, lubricants for bearings and other moving parts must be very carefully selected. To satisfactorily resist oxidation, heavy pressures, and reduce wear on bearing surfaces, 'dag' colloidal graphite has been accepted as having all of the properties necessary to maintenance-free performance.

Dependable bearing lubrication of pattern carriages on shell molding machines is a "must" at Production Pattern and Foundry Co., Chicopee, Massachusetts. With five shell molding machines operating three shifts a day to supply their casting floor, uninterrupted service has to be maintained. These carriages shuttle back and forth between curing ovens and investing box . . . from 900° F. to 400° F. The three friction points that require special lubrication in this operation are: axle bearings for the 4-wheel pattern carriages; the pivots for the two-hitch mounts at each end of the carriages; and the link pins of the roller chains which propel the carriages back and forth across the bed of the machine. 'Oildag' — colloidal graphite in a petroleum oil carrier — is applied once a day to the bearings and pivot points, every 12 hours to the link pins. The result: where conventional oils and greases before had decomposed leaving a tarry residue or a non-lubricating soap, 'Oildag' retained its lubricating properties under both heat and load pressures. 'Oildag' is economical and heat resistant . . . necessary characteristics to its use in this application. With regular use, lubricants containing 'dag' colloidal graphite form a low-friction graphoid film that adheres tenaciously to the bearing surface, effectively resisting rupture, oxidation, and wear. Proof of this effectiveness? Life of these bearing segments now runs about 400 hours . . . *eight times longer than before!* According to Earl W. Jahn, President of Production Pattern and Foundry, "Until we discovered the dependable high-temperature lubrication performance provided by the Oildag mixture, we just weren't in business."



24 hours a day, at temperatures up to 900° F., Oildag provides maintenance-free lubrication of shell mold pattern carriages at Production Pattern & Foundry.



Studebaker-Packard Corporation's Foundry Department finds 'dag' No. 2404 saves on material, labor, and conveyor wear.

'dag' colloidal graphite solves conveyor lubrication for Studebaker-Packard. Their Foundry Department needed the answer to more efficient conveyor lubrication in baking ovens where operating temperatures ranged from 250° to 450° F. Heat caused gumming and partial decomposition of both the heavy greases and conventional non-graphited oils used. The residual deposit left resulted in "frozen" bearings requiring excessive down-time, as well as parts replacement.

By applying a dilution of 'dag' No. 2404—colloidal graphite in a mineral spirits carrier—on bearings, bushings, races and other critical parts, Studebaker-Packard found the ready-made solution. Application of these microscopically-fine particles was easily made through their automatic spray system. The excellent wetting action of the carrier deposited an unbroken film on all critical surfaces. The resulting dry film prevented accumulation of abrasive dust or sticky residue, allowing worthwhile savings in lubricant, labor, and conveyor wear. For further information on high temperature applications write for Bulletins 423 and 424. Address Dept. LE-68.

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PRODUCT LITERATURE

HYDRAULIC TUBING BROCHURE

A 10-page illustrated brochure outlines the advantages of Republic Steel's electric resistance welded hydraulic line tubing and highlights how the high quality fatigue resisting pressure tubing for hydraulic line service can be easily and uniformly bent and the tubing flared and assembled. In addition to explaining points of manufacture, the new literature provides a complete list of specifications and features a table of recommended working pressures and size ranges. The brochure is available from Republic Steel Co., Steel & Tubes Div., 224 E. 131st St., Cleveland 8, Ohio.

ABC'S OF COLLOIDAL GRAPHITE

"The ABC's of Colloidal Dispersions," has been issued by Acheson Colloids Co., Port Huron, Mich., Division of Acheson Industries, Ins., manufacturers of the "dag" family of dispersions. The 12-page booklet provides the answers to many of the questions frequently asked about colloids with story, drawings and pictures. The back cover lists technical bulletins available from the company on the uses of colloidal graphite and other materials which have achieved wide recognition for the Port Huron company. Sections of the booklet include "What Is Graphite?", "What is Colloidal Graphite?," "Why is a Colloidal Dispersion Better Than a Dry Powder?", "Why Is Graphite Dispersed in Various Fluids?", "What is Molybdenum Disulfide?," and "What Other Solids Do We Disperse?" For a copy of the "ABC's" booklet, write Acheson Colloids Co., Port Huron, Mich.

NEW CYCLOBLOWER BROCHURE

The U. S. Hoffman Machinery Corp. has announced publication of a new, two color, four page brochure which describes the Hoffman CycloBlower . . . an axial flow, positive displacement blower/compressor for outstanding pressure, vacuum or combination service. Outstanding features of the CycloBlower are: clean air/gas delivery, efficient, shock-free compression, high capacity combined with low unit weight, dependable operation and long life. The brochure describing construction features, applications and advantages is entitled CB 157, and may be obtained from the U. S. Hoffman Industrial Divisions upon request.

ATOMIC INSTRUMENT DATA

A complete, new line of atomic instrument systems to measure and analyze radioisotopes in industrial, medical and biological applications is described in the Atomic Systems Catalog A-2 just published by Baird-Atomic, Inc., Cambridge, Mass. Four new scintillation spectrometers are described in addition to the instrument assemblies making up the Basic Laboratory and the ultra-precise University Series Laboratory for scintillation, proportional and geiger counting. Send requests for Atomic Systems Catalog A-2 to Baird-Atomic, Inc., Cambridge, Mass.

AID TO FLAME-CUTTING

A new folder, "Cut Your Flame-Cutting Costs," is available from Linde Company, Division of Union Carbide Corporation. The 12-page folder describes several ways in which quality nozzle construction and proper nozzle selection can reduce gas consumption and nozzle replacement, the primary cost factors in all flame-cutting operations. The advantages of chrome-plating and swaged construction are also described. Copies of the folder may be obtained by writing to Linde Company, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, New York. Ask for Form 1057.

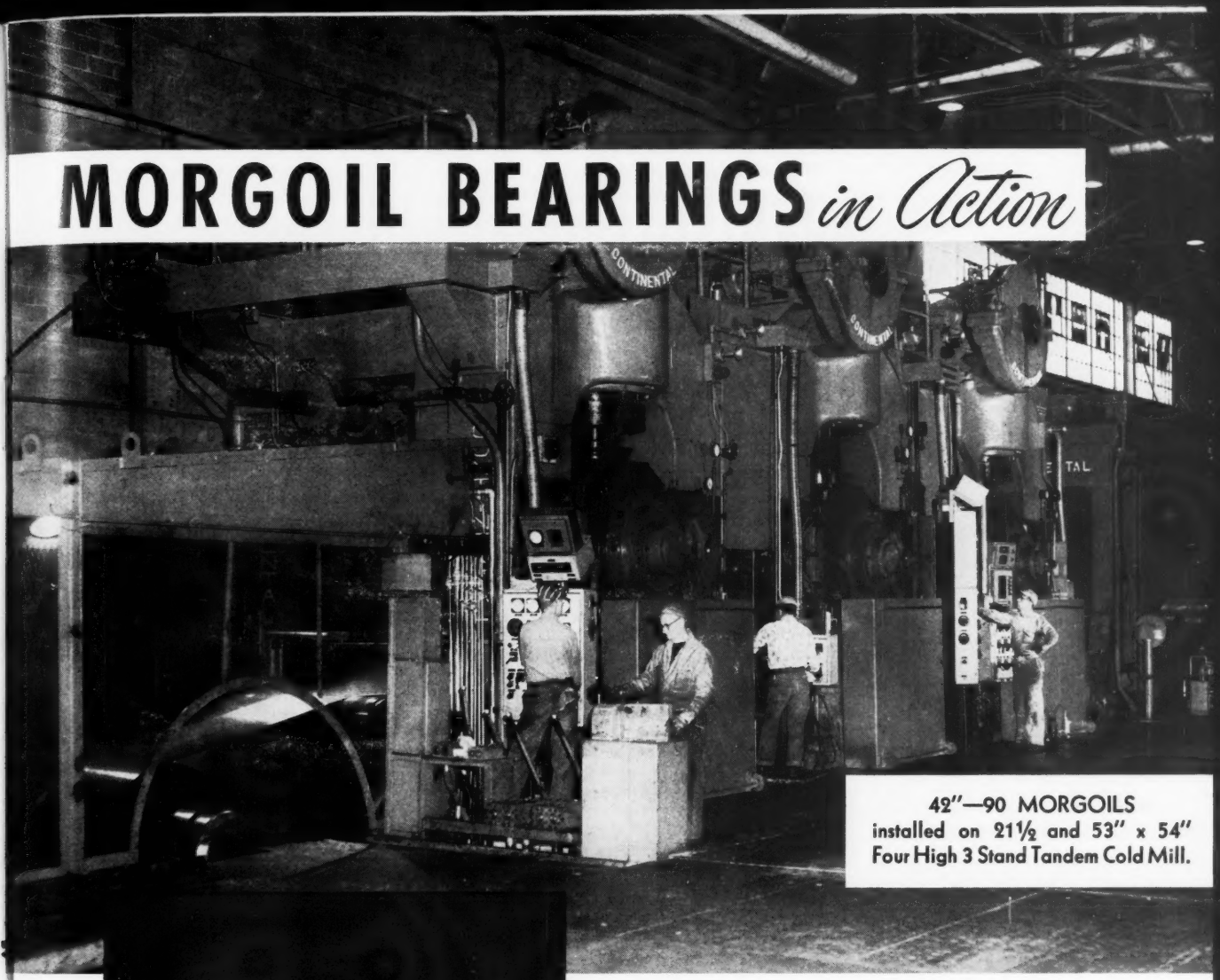
SILICONES BOOKLET

Major General Electric silicone products and their uses are discussed in CDS-129, a new eight-page catalog now available from the Silicone Products Department of the General Electric Company, Waterford, N. Y. Among the silicone materials for which data and descriptions are given are rubber, fluids, resins, water repellents, electrical insulation, release agents, lubricants, paint vehicles, and anti-foam agents. In addition to basic product and application information, CDS-129 also lists G-E literature providing detailed reports about specific silicones and their applications in the aircraft, electrical, automotive, textile, chemical, paint, polish, rubber, construction and other industries.

A-6 FRICTION TESTER DATA

The new Hohman A-6 friction and wear tester is described and illustrated in a bulletin published by the Hohman Plating and Mfg. Co. The tester is a standard instrument used for the simulation of most types or combinations of wear, heat and atmospheric conditions that are encountered by solid lubricants. It can also be used for the wear or friction testing of many plastics and fibrous materials as well as oils and greases. For a copy of the bulletin, or further information on solid lubricants, write to Hohman Plating and Mfg. Co., 814 Vermont Ave., Dayton 4, Ohio.

MORGOIL BEARINGS *in Action*



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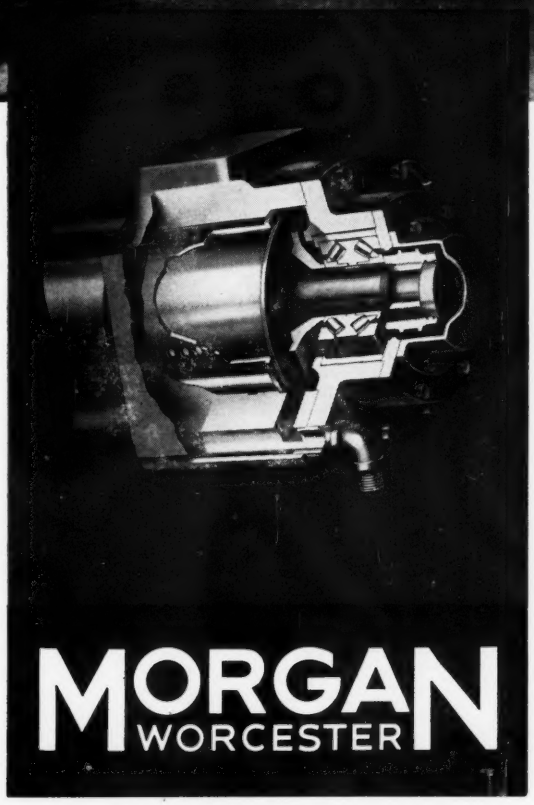

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MB-33

AMERICAN SOCIETY OF LUBRICATION ENGINEERS

Statement of Cash Receipts and Disbursements

Year Ended December 31, 1957

RECEIPTS:		
Membership Dues —		
Individual	$53,744.15	
Industrial	6,300.00	
Sectional Sustaining	2,301.75	$ 62,345.90
Sale of Publications —		
Lubrication Engineering subscription income	$ 8,597.26	
Lubrication Engineering sales, preprints, etc.	5,119.08	
Other publication sales	2,858.37	16,574.71
Exhibit Funds —		
1957 show collected in 1956, transferred to free surplus in 1957	$ 5,203.00	
1957 show collected in 1957	5,485.10	10,688.10
Annual Meeting —		
Guest registration and banquet tickets	$10,129.60	
Lubrication Engineering course	915.00	11,044.60
Advertising Income		43,275.50
Interest and Sundry Income		2,289.77
Joint Conference Income		3,412.10
TOTAL		$149,630.68
DISBURSEMENTS:		
Salaries, commissions, fees	$41,592.51	
Cost of publications	43,269.36	
Office furniture and equipment purchases	2,076.25	
Office supplies and expense	1,839.13	
Railroad fares and travel	2,256.70	
Section payments	7,695.79	
Rent	3,420.00	
Telephone and telegraph	1,460.17	
Dues, donations and subscriptions	166.65	
Legal and auditing expense	525.00	
Federal insurance contributions and unemployment tax	1,163.92	
Sundry merchandise purchases	33.34	
Payment for journal bearing research	19.75	
Annual meeting expense	10,118.06	
Awards expense	301.81	
Exhibit expense —		
1957 show paid in 1956	$ 244.40	
1957 show paid in 1957	1,825.19	2,069.59
Postage and express	2,567.29	
Stationary and printing (excluding Exhibit costs)	2,116.51	
Group and other insurance	723.01	
Educational program	192.87	
Joint conference expense	1,555.60	
Directors' and committee meeting expense	458.70	
Contingencies	614.86	
Personnel service fees	286.10	
Advertising commissions	6,882.50	
Promotional material	984.39	134,389.86
Excess of receipts over disbursements		$ 15,240.82
Adding 1957 Membership dues collected in 1956; Subtracting 1958 dues collected in 1957 — Excess of receipts over disbursements representing net increase in free surplus		$ 592.82

Balance Sheet — December 31, 1957

ASSETS

WORKING CAPITAL ASSETS:		
Cash on deposit and on hand —		
Bank checking account	$15,299.65	
Bank savings account	124.62	
Petty cash fund	35.00	
Travel advance fund	250.00	
Total working capital assets		$15,709.27
RESERVE FUND ASSETS:		
Savings and loan deposits	$31,751.52	
Investment in United States Treasury Bonds — at cost	14,709.11	46,460.63
OFFICE FURNITURE AND EQUIPMENT:		
At cost	$10,651.64	
Less: Allowance for depreciation	3,383.20	
Net book value		7,268.44
		$69,438.34

LIABILITIES AND SURPLUS

LIABILITIES:		
Account payable as trustee — award fund contributed by W. D. Hodson, Jr.	$ 25.00	
Account payable — payroll withholding taxes	524.05	
Total liabilities		$ 549.05
SURPLUS:		
Surplus reserve — Unearned rentals collected during 1957 for 1958 Exhibit — net of expenses paid	$ 4,033.05	
Free surplus	57,587.80	
Surplus invested in office furniture and equipment	7,268.44	
Total surplus		68,889.29
		$69,438.34

NOTE: *The above statement has been prepared on the basis of cash receipts and disbursements.*

THE ABOVE REPORT IS IN AGREEMENT WITH THE AUDITORS' REPORT AS PREPARED BY C. L. GRIMES & CO. CERTIFIED PUBLIC ACCOUNTANTS.

Admiring charter awarded to newly-formed Richmond section are (left to right) J. E. Connelly, secretary; L. M. Bunting, treasurer; O. L. Miller, chairman; J. D. Lykins, national president, and E. J. Remson Jr., vice chairman.

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Shell Oil Co.	250
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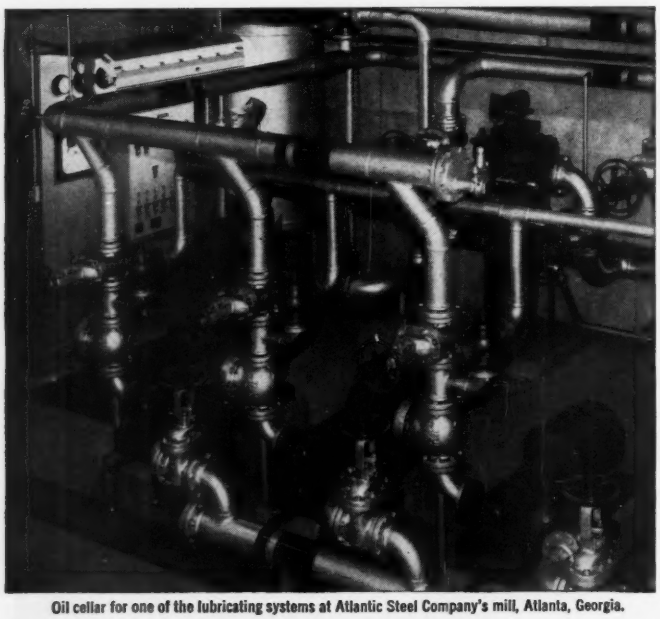
Union Carbide & Carbon Chemicals Co.	276

Dravo-DeLaval lubrication systems for Atlantic Steel



Oil cellar for one of the lubricating systems at Atlantic Steel Company's mill, Atlanta, Georgia.

Three Dravo-designed mill lubrication systems automatically feed 475 gpm of oil to gears and bearings of a new high-speed Atlantic Steel Company rod and bar mill at Atlanta, Georgia. The entire network includes temperature and pressure controls, filters, oil coolers, pressure reducing stations, pumps and control panels.

Supplying oil at carefully controlled pressures and temperatures, the smaller of the three systems lubricates gears on a reheating furnace. Another handles the roll stands of the mill and the third, a two branch arrangement, uses one branch when 15 of the 21 stands are at work, a second operates when the remaining six go into operation.

For full information on efficient, low-maintenance lubrication systems, write for Bulletin No. 1450, Dravo Corporation, Pittsburgh 22, Pennsylvania.

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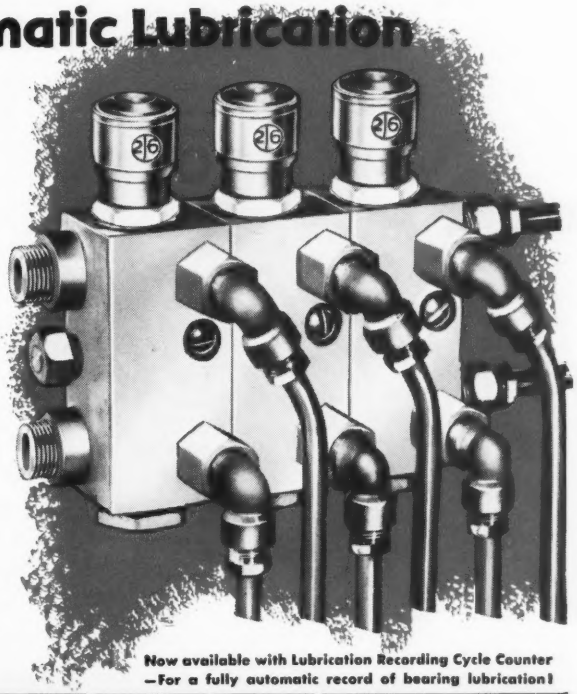
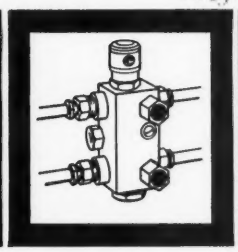
- Delivers exact amount of lubricant to bearing.



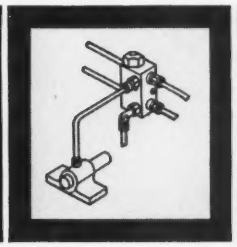
Now available with Lubrication Recording Cycle Counter —For a fully automatic record of bearing lubrication!

Can be designed into any machine, in 4 EASY STEPS!

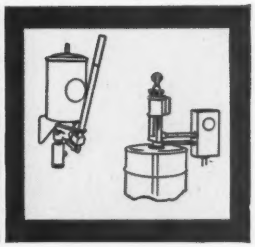
1. Remove grease cups or grease fittings.



2. Connect each valve in system to its two lubricant supply lines.



3. Connect valve outlets to inlet of bearings. (Each valve serves two bearings.)



4. Provide central pump for supplying lubricant to system.

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